

REMEDIATION WORK PLAN

Geocel Corporation 2504 Marina Drive Elkhart, Indiana VRP#6070601

Prepared For:



Prepared By:

Roberts Environmental Services, LLC 2112 Carmen Court Goshen, Indiana 46526

Reference: #40

RES Project No. 06-1 August 27, 200



REMEDIATION WORK PLAN

Geocel Corporation 53280 Marina Drive Elkhart, Indiana VRP#6070601

Prepared For:

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2504 Marina Drive Elkhart, Indiana 46514

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Indiana Department of Environmental Management

Office of Land Quality - Voluntary Remediation Program

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RES Project No. 06-10246-42

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1.0 INTRODUCTION

The Geocel Corporation ("Geocel") facility is located at 2504 Marina Drive (formerly 53280 Marina Drive), in Elkhart, Indiana, 46515 (hereinafter referred to as the "Site"). The Indiana Department of Environmental Management (IDEM) Voluntary Remediation Program (VRP) site identification number is 6070601. The approximate geographic coordinates of the middle of the Site are 41.7199° North and -85.9160° West (NAD83).

Two (2) primary areas of contamination have been identified at the Site: a western area of concern ("WAC") and an eastern area of concern ("EAC"). Soil and ground water samples collected in November 2006 indicated a potential release from the area of one or more former underground storage tank (UST) systems located near the southwestern exterior of the on-Site building (WAC). Subsequent investigation activities also indicated a separate release on the southeastern portion of the Site (EAC). The volume of the releases is unknown. However, the absence of free product and the limited migration of the EAC plume appear to indicate that this release is most likely the result of a surficial spill of limited volume, while the greater horizontal and vertical extent of contamination found to be associated with the WAC plume appear to indicate that this release involved more significant quantities of contaminants and possibly occurred below grade. Ground water flow patterns in the area of the Site suggest a southwesterly ground water flow to southerly ground water flow farther south from the Site. The WAC plume is approximately 250-feet wide north of County Road 106 and approximately 500-feet wide south of County Road 106 at its widest points. The WAC plume is approximately 2,800-feet long. The EAC plume is approximately 125-feet wide by approximately 250-feet long. The areas of contamination have been defined by the limits of contaminant concentrations that are greater than or equal to IDEM Risk-Integrated System of Closures (RISC) residential default closure levels (RDCLs) (hereinafter referred to as the "Impacted Area"). Several figures included in the Investigation Report (Supplement #2) depict the extent of the Impacted Area.

The primary chemicals of concern ("COCs") in the EAC are chlorinated solvents (i.e., primarily tetrachloroethylene–PERC), while the primary COCs in the WAC are chlorinated solvents commingled with aromatic hydrocarbons (i.e., toluene, ethylbenzene, trimethylbenzenes, and xylene). Chlorinated degradation products of PERC, such as trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-DCE), and vinyl chloride (VC) are also present at the Site, primarily in the WAC. Some semi-volatile organic compounds (SVOCs) have also been detected on-Site and total petroleum hydrocarbons (TPHs) in the gasoline range organics (GRO) and the extended range organics (ERO) have been detected on-Site and off-Site. Primary COCs in the portion of the WAC located south of County Road 106 (residential area) include cis-DCE and VC.

A. Background & Sources of Contamination

Site Name, Address, & Telephone Number

Roberts Environmental Services, LLC (RES) has completed various subsurface investigation activities at the Site located at 2504 Marina Drive, Elkhart, Indiana, 46515. The project "Study Area" includes the Geocel facility property and areas south of the Geocel facility included in the investigation activities. Figure 1 in the Investigation Report depicts the Site vicinity on an USGS 7.5-minute topographic map (Elkhart, Indiana). The Indiana Department of Environmental Management (IDEM) Voluntary Remediation Program (VRP) Site identification number is 6070601. Geocel Corporation can be contacted via telephone at (800) 348-7615 or via U.S. Postal service at P.O. Box 398, Elkhart, Indiana 46515. The primary Site contact is Mr. Don Krabill, President.

Current Owner & Contact Information

The current owner of the Site is Geocel Holdings Corporation, which acquired the Site in September 2000. Geocel Holdings Corporation can be contacted at the same address and telephone number listed above.

Historical Summary of Site Ownership

The following table lists the historical ownership as defined utilizing readily available records:

HISTORICAL OWNERSHIP				
Owner	Ownership Dates			
Geocel Holding Corporation	September 2000 to Present			
Geocel Limited, Inc.	September 1977 to September 2000			
Allan Ludwig & David Miller	August 1977 to September 1977			
Newberry & Faye Cooper	April 1937 to August 1977			
Federal Land Bank of Louisville	February 1933 to April 1937			
Eva Brown	September 1927 to February 1933			
Ollie Sowers	October 1922 to September 1927			
Charles Fisher	March 1921 to October 1922			
John Grames	*Before 1915 to March 1921			

^{*} Further Data Not Practically Reviewable

Type of Facility & Operations

As described in the Investigation Report, the Site has been used for industrial purposes since the original western portion of the building was built in 1977/1978. It appears the Site was either vacant or used for agricultural purposes (i.e., row cropping) before this time. The Site consists of a 55,000 square feet production building with a two-story office area located in the northwestern portion of the building. The original western portion of the manufacturing building (western two-thirds of the building) was constructed in 1977/1978 and an addition was constructed on the eastern portion of the Site (eastern one-third of the building) in 2004/2005. A 2005 aerial photograph showing the Site is provided as Figure 3 and a facility survey is provided in Figure 4 of the Investigation Report.

Large quantities of chemicals are stored and utilized at the Site including bulk storage tanks, 55-gallon drums, and smaller containers or packages of adhesives, caulks, plasticizers, and oils/greases. The Site is considered a RCRA large quantity generator of hazardous wastes, primarily due to waste flammable liquids and solvents. Currently, the facility also has bulk storage of tetrachloroethylene and aromatic hydrocarbons solvents stored in above ground storage tanks ("ASTs") near the southwestern exterior of the building, which replaced the former USTs. Operations at the Site involve the manufacturing and packaging of sealants, caulks, and adhesives (SIC Code 2891). General processes include product formulation/mixing and packaging into tubes and other containers.

Site Contact for VRP Process

The primary Site contact is Mr. Don Krabill, President of Geocel. Roberts Environmental Services, LLC is currently managing the investigation and remediation activities at the Site. Contact information for RES is provided on the cover page of this report.

Overview of Contaminant Sources/Spill History

No significant historical spills or releases have been documented at the Site. The nature of the release(s) at the Site is unknown. As previously stated, the WAC and the EAC are the primary areas of contamination. Soil and ground water samples collected in November 2006 indicated a potential release from one or more former UST systems located near the southwestern exterior of the on-Site building (WAC). These USTs were reportedly removed in 1986. Subsequent investigation activities also indicated a separate release on the southeastern portion of the Site (EAC). The volume of the releases is unknown. However, the absence of free product and the limited migration of the EAC plume appear to indicate that this release is most likely the result of a surficial spill of limited volume, while the greater horizontal and vertical extent of contamination identified with the WAC plume appear to indicate that this release involved more significant quantities of contaminants. The contamination was reported to the Elkhart County Health Department (ECHD) on June 7, 2007, and the VRP application for the Site was mailed to IDEM on June 8, 2007. The IDEM VRP #6070601 was ultimately assigned to the Site.

The COCs in the EAC are chlorinated solvents (i.e., primarily tetrachloroethylene-PERC), while the primary COCs in the WAC appear to be chlorinated solvents (PERC and its degradation products)

commingled with aromatic hydrocarbons (i.e., toluene, ethylbenzene, trimethylbenzenes, and xylene). Chlorinated degradation products of PERC, such as trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-DCE), and vinyl chloride (VC) are also present in the Study Area, primarily in the WAC. Some semi-volatile organic compounds (SVOCs) have also been detected on-Site and total petroleum hydrocarbons (TPHs) in the gasoline range organics (GRO) and the extended range organics (ERO) have been detected on-Site and off-Site. COCs in the portion of the WAC located south of County Road 106 (residential area) are primarily limited to cis-DCE and VC. The Tables in Section 2.0 part B list the primary COCs detected within the study area.

B. Supporting Documentation

Relevant Previous Reports

Previous investigations include two (2) prior Phase I ESAs prepared by Envirocorp Services & Technology, Inc. of South Bend, Indiana. The Phase I ESA dated February 18, 1992, listed several items in the conclusions of the report, including the former presence of underground storage tanks (USTs) at the Site and large amounts of chemicals stored at the Site. The Phase I ESA dated December 1998 listed several Recognized Environmental Conditions in connection with the Site, including: floor drains from the laboratory exiting to the septic system; former USTs at the Site; contaminants detected in the septic tank during sampling events; and the presence of large quantities of chemicals at the Site. RES completed a Phase I ESA at the Site (dated October 20, 2006) that preceded the subsequent subsurface investigation activities described in this report.

Data & Documentation Regarding this Site

References cited in this report are listed in Section 4.0. A Quality Assurance Project Plan (QAPP) that includes a sampling and analysis plan (SAP), a Health and Safety Plan (HASP), and laboratory QA/QC plan is provided in Supplement #1. The Phase I Environmental Site Assessment (ESA) of the Site by RES in October 2006 was provided with the original VRP application submittal. An Investigation Report and a Community Relations Plan are also included in this report as Supplements #2 and #3, respectively. The majority of figures and tables referenced in this report are included as part of the Investigation Report. A Vapor Intrusion Investigation report dated March 19, 2008, was previously prepared and submitted to IDEM. A copy of the Vapor Intrusion Investigation Report is included as Supplement #4 of this report.

C. Remedial Action Objectives

Remediation & Cleanup Objectives

Ground water is the primary affected media in the project Study Area. Some soil contamination is present within the WAC and EAC source zones on-Site. Outside of the source zones, only saturated soil is impacted. As described in Section 2.0-D of the Investigation Report, surface water from the pond located directly north of Rye Court (approximate centerline of plume) was sampled and

analyzed for VOCs in July 2007 and did not contain any detectable concentrations of VOCs. Additionally, several shallow wells and temporary well sampling locations located across the Study Area indicate that shallow ground water (i.e., the top 4.0 to 10.0-feet of water table) is not contaminated at off-Site locations. As such, this information coupled with two (2) rounds of vapor intrusion sampling conducted in the Meadow Farms neighborhood, suggest that vapor intrusion pathways are not complete at off-Site locations. The primary exposure pathway within the Study Area is ingestion/inhalation of ground water, which has been or is in the process of being mitigated by the installation of municipal water throughout the area. As such, primary remedial objectives consist of documenting a stable or shrinking plume (i.e., stability monitoring). RISC RDCLs and IDCLs will be used to guide the monitoring activities.

Work Items Planned for Remediation

No active contaminant remediation has been initiated at the Site to date. However, potential receptor mitigation activities have taken place since June 2007. These activities have included the following:

- The continual supply of bottled drinking water to 115 residential homes located south of County Road 106;
- The installation and maintenance of granular activated carbon ("GAC") filtration systems in twenty-five (25) homes with detections of volatile organic compounds ("VOCs") greater than 50% of the U.S.EPA maximum contaminant level ("MCL"). Detections primarily consisted of vinyl chloride at levels greater than or equal to 1.0 microgram per liter (ug/l); and
- The installation/connection of municipal water to approximately 100 homes located south of County Road 106 has been initiated by Geocel. These project activities started in July 2008 and are scheduled for completion in October 2008. Bottled water supplies and GAC filters will be discontinued after municipal water connections are completed.

Work items planned for the remediation include active remediation in source areas and far northern portions of the plume followed by plume stability monitoring. Cleanup objectives for the project Study Area will be a stable or shrinking plume for all VOC, SVOC, TPH-GRO, and TPH-ERO contaminants in the ground water.

2.0 INVESTIGATION ACTIVITIES

Section 2.0 summarizes information that is described in detail in the Investigation Report. The Investigation Report has been submitted as Supplement #2 of this report.

A. Summary of Information Used to Select Remedy

Baseline Assessment & Literature Search

The topography of the Site vicinity is generally flat with a slight slope to the south-southeast. The Site has an approximate elevation of 770 feet above mean sea level (USGS Topographic Map—Elkhart, Indiana). A drainage swale/ditch is located along the southern property boundary and along the eastern property boundary. The nearest surface water bodies include the on-Site drainage ditch, which is intermittent, Heaton Lake, located approximately 1.0-mile north of the Site, Puterbaugh Creek, located approximately 1.25-miles west of the Site, and the St. Joseph River, located approximately 1.5-miles south of the Site. Some small natural and manmade ponds and wetland-type areas are also located south of County Road 106. No portions of the Study Area are located within a floodplain.

According to the Soil Survey of Elkhart County, Indiana (U.S. Department of Agriculture (USDA), 2000), surficial soils on the Site consist of the urban land subsection of the Brems Complex (UdoA). Urban land designated soils have been reworked to the extent that they may no longer match the typical type-section description. However, Brems Series soils are described as loamy sands that formed from glacial outwash deposits. These soils are gently sloping and occupy swells and outwash plains. Dark brown loamy sands exist in the top 27-inches of soil. The soil progressively becomes sandier at depths beyond the surficial loamy sands. Brems soils are moderately well-drained with a low available water capacity.

Surficial geology in the general vicinity of the Site is represented by outwash deposits of gravel, sand, and silt (Schneider and Keller, 1972). These sediments are associated with the outwash facies of the Atherton Formation in Indiana. Bedrock subcrops at an approximate depth of 175-feet beneath the surficial unconsolidated deposits and consists of Sunbury and Ellsworth Shales.

According to Water Resources Availability in the St. Joseph River Basin, Indiana (Indiana Department of Natural Resources - IDNR, 1987), the Study Area is located within the St. Joseph Aquifer System. The IDNR basin report indicates the regional and local ground water flow direction is south-southwesterly towards the St. Joseph River, which is located approximately 1.5-miles south of the Site. Production wells in the area or other local subsurface anomalies may also have a slight affect on the ground water flow direction. The St. Joseph Aquifer System consists of thick sand and gravel deposits that have excellent ground water availability (100 to 1,500 gallons per minute (gpm)). According to IDNR, the St. Joseph Aquifer is susceptible to contamination and is a U.S.EPA designated sole-source aquifer.

In general, the depth to ground water at the Site is approximately 6.0-feet below surface grade (bsg), but can vary between 2.0-feet and 12.0-feet bsg across the entire Study Area. Soils at the Site tend to

match the soil survey descriptions and generally consist of silty sands near the surface with sands and gravels at depth. Some fine sand and silt layers may be encountered at depths of approximately 30 to 45 feet bsg and below 50 to 60 feet bsg. A 2.0 to 5.0 feet thick gray clay layer is present at approximately 140-feet bsg and shale bedrock is encountered at a depth of approximately 200-feet bsg. The primary aquifer layers in the Study Area consist of sand and gravel layers at depths of approximately 12 to 30 feet bsg (intermediate aquifer zone) and 40 to 50 feet bsg (deep aquifer zone). Contaminated ground water at off-Site locations is generally identified in these two (2) primary aquifer zones.

The Site is part of the northeast ¼ of Section 26, Township 38 North, Range 5 East, Osolo Township, Elkhart County, Indiana. As of early 2008, the Site and areas north of County Road 106 have been annexed into the City of Elkhart. The Site is identified as Tax Parcel No. 20-02-26-251-001.000-026 and encompasses a total of approximately 4.78-acres. The approximate geographic coordinates of the middle of the Site are 41.7199° North and -85.9160° West or UTM. The location of the Site is depicted in Figure 1 of the Investigation Report.

The Site and the entire Study Area will be provided drinking water via City of Elkhart municipal water system once the water connections in the residential neighborhood are completed in October 2008. The Site has utilized municipal water since approximately 1990. None of City of Elkhart's Wellhead Protection Areas (WHPAs) overlap the Study Area (5-year time-of-travel). A WHPA proximity determination letter is included in Appendix G of the Investigation Report.

A preliminary evaluation of geologically and socially susceptible areas reveals that no such areas are located within the immediate vicinity of the Study Area (i.e. schools, karst areas, etc.). These potential susceptible areas were evaluated using topographic maps, aerial photography, and windshield surveys from public roads. Nearby sensitive institutions were also researched as part of the Community Relations Plan included in Supplement #3. As previously stated, some wetland-type areas and ponds are located south of County Road 106 and preliminary sampling and analysis indicates these areas have not been impacted (no VOCs detected).

Extent of Subsurface Work

To date, 76 Geoprobe® borings have been installed that included temporary well ground water samples (identification numbers of GP-xx). Six (6) additional soil sample only borings have also been installed using a hand auger sampling device (identification numbers of SB-xx). One (1) deep background geologic boring (depth of 200-feet; BG-1) and two (2) deep continuous multi-channel tubing (CMT) ground water screening borings (depths of approximately 145-feet; WCMT and ECMT) have been installed utilizing a sonic drill rig. Nine (9) deep membrane interface probe (MIP) screening borings were also completed. Additionally, numerous monitoring wells have been installed across the Study Area primarily utilizing a direct-push drill rig with pre-packed 1.0-inch diameter screens. To date, 119 monitoring wells have been completed across the Study Area, including 39 on-Site wells and 80 off-Site wells. Further, 115 residential water wells were sampled and analyzed in June/July 2007 and 93 residential wells were re-sampled in August 2007. Private water wells at industrial facilities located north of County Road 106 have also been sampled and analyzed, including: two (2) private water wells at the Keyline Sales property (2 separate events); a

private water well at the Marine Fasteners property (2 separate events); an irrigation well at the Hadley property (former Dygert Seating); and an irrigation well at the ACT property. Soil and ground water sampling procedures are detailed in the quality assurance project plan (QAPP) provided in Supplement #1. Two (2) separate rounds of vapor intrusion sampling were also conducted in seven (7) residential homes located south of County Road 106. Boring Logs/Monitoring Well Construction Logs are provided in Appendix C of the Investigation Report (Supplement #2). Field Screening results are provided on the Boring Logs. Boring, monitoring well, and other sample locations are shown on Figures 3, 4, and 5 in the Investigation Report.

B. Summary of Site Investigation

Identification of All Contaminants

The primary COCs in the EAC are chlorinated solvents (i.e., primarily tetrachloroethylene–PERC), while the primary COCs in the WAC appear to be chlorinated solvents (PERC and its degradation products) commingled with aromatic hydrocarbons (i.e., toluene, ethylbenzene, trimethylbenzenes, and xylene). Chlorinated degradation products of PERC, such as TCE, cis-DCE, and VC are also present in the Study Area, primarily in the WAC. Some semi-volatile organic compounds (SVOCs) have also been detected on-Site and TPHs have been detected on-Site and off-Site. Primary COCs in the portion of the WAC located south of County Road 106 (residential area) include cis-DCE and VC.

Material Safety Data Sheets (MSDSs) and international safety cards (as represented by tetrachloroethylene (PERC), trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-DCE), vinyl chloride (VC), and HiSol10 (petroleum hydrocarbon mixture)) are included in Appendix A of the QAPP. Fire and explosion hazards are associated with petroleum hydrocarbons and solvents. Inhalation hazards may also exist at high concentrations. However, the nature, degradation, and location of the contaminants at the Site would minimize fire and/or explosion hazards. Other chemical/physical properties of the COCs are described in Section 3.0 of the Investigation Report supplement.

Vinyl chloride is considered a known carcinogen over a lifetime of exposure. The other chlorinated solvents can affect the central nervous system, liver, kidneys, and many are suspect carcinogens. Some toxicological data is also listed on the safety card provided in the QAPP. The primary exposure pathways are ingestion/inhalation from ground water and/or contact with contaminated soil at the Geocel facility. Ground water ingestion pathways have been mitigated by the installation of municipal water and source area soils at the Geocel facility are capped with asphalt or concrete. As such, potential effects associated with residual contamination after remediation activities take place will be minimal.

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Summary of Site-Specific Geology & Hydrogeology

As shown on the Site boring logs and geologic cross-sections included in the Investigation Report supplement, sitewide stratigraphy generally consists of silty sands near the surface with sands and gravels at depth. Some fine sand and silt layers may be encountered at depths of approximately 30 to 45 feet bsg (intermediate fine/medium sand layer) and below 50 to 60 feet bsg (deep fine sand layer). A 2.0 to 5.0 feet thick gray clay layer is present at approximately 140-feet bsg and shale bedrock is encountered a depth of approximately 200-feet bsg. The primary aquifer layers at the Site consist of coarse sand and gravel layers at depths of approximately 12 to 30 feet bsg (intermediate aquifer zone) and 40 to 50 feet bsg (deep aquifer zone).

Sitewide Hydrogeology

The depth to ground water across the Study Area varies between 2.0 to 12-feet bsg. The primary aquifer zones, located between 12 to 30 feet bsg (intermediate aquifer zone) and 40 to 50 feet bsg (deep aquifer zone), consist of approximately 10 to 30% gravel within a medium/coarse sand matrix. Fine to medium sands are present between the intermediate and deep aguifer zones (intermediate fine/medium sand layer) and fine sands to fine silty sands are present beneath the deep aquifer zone (deep fine sand layer). Site-specific grain-size analysis, pneumatic slug tests, and a mini-aquifer pumping test indicate that the intermediate aquifer zone hydraulic conductivity ranges from approximately 100-feet/day to over 400-feet/day, depending on the exact screened interval being analyzed, and the deep aquifer zone hydraulic conductivity is likely near 300 to 375 feet/day. The intermediate fine/medium sand layer hydraulic conductivity is approximately 80 feet/day, while the deep fine sand layer hydraulic conductivity is approximately 20 feet/day. Average porosity across the Study Area was calculated at approximately 28% for the primary aquifer zones and 30% for the finer-grained layers. Static water level measurement data, graphically presented in Figure 8 of the Investigation Report using only intermediate and shallow well measurements, shows the Site ground water flow direction is approximately south 15° west at a hydraulic gradient (i) of approximately 0.001 feet/feet at locations north of County Road 106. South of County Road 106, the ground water flow begins to shift due south with a slightly steeper hydraulic gradient of 0.002 to 0.003 feet/feet. Using the above preliminary data, the approximate ground water flow velocity in the primary aquifer zones is 1.34 ft/day.

Discussion of Sources of Contamination

Soil and ground water samples indicate a potential release from the area of one or more former UST systems located near the southwestern exterior of the on-Site building (WAC). These USTs were removed in 1986. The original source area COCs appear to be a petroleum hydrocarbon mixture (HiSol10) and virgin PERC in the WAC and PERC alone in the EAC. The HiSol10 petroleum hydrocarbon mixture basically consists of mineral spirits with added aromatic hydrocarbons (ethylbenzene, toluene, and xylenes). The other chlorinated solvents in the WAC plume (TCE, cis-DCE, and VC) appear to be a result of reductive dechlorination of the original PERC, which consists of four (4) chlorine atoms bound to two (2) double-bonded carbon atoms. Reductive dechlorination tends to occur in anaerobic environments (little to no oxygen availability). Since the contamination

in the EAC plume appears to be the result of some type of surficial release, little to no reductive dechlorination is observed in this relatively oxygen-rich water table aquifer.

Summary of Extent of Contamination

Soil. The extent of soil contamination identified above RISC RDCLs is shown on Figure 20 of the Investigation Report. The horizontal extent of non-saturated soil contamination appears to be limited to areas very near the suspected historical source area in the WAC (i.e., the former UST basin) and the suspected historical source area in the EAC (near boring GP-40). Some soil contamination is also present under the building in the WAC. However, this soil contamination may be the result of high concentrations of ground water contamination in this area producing vapors that are trapped in the soil under the concrete and asphalt slabs or the temporary change in ground water flow directions due to ground water mounding within the drainage ditch on the southern property boundary.

Ground Water. No LNAPL or DNAPL was observed in any of the borings or monitoring wells installed across the Study Area. The horizontal extent of primary COC dissolved ground water contamination across the Site is depicted on Figures 21 through 30 of the Investigation Report, while the vertical extent of contamination is graphically depicted on the geologic cross-sections in Figures 13-19 of the Investigation Report. The combined horizontal extent of the Impacted Area of contamination encompasses approximately 24.6-acres. As shown in the figures, petroleum hydrocarbon contamination is limited to the WAC plume and at locations relatively near the original source area. The vast majority of petroleum hydrocarbon-related contamination is limited to on-Site areas (i.e., the actual Geocel property). Chlorinated solvent contamination is present in both the WAC and EAC plumes. However, PERC is the primary COC in the EAC as little to no other chlorinated solvents are present at this location (possibly due to the contamination occurring in the relatively oxygen-rich water table aquifer where negligible reductive dechlorination takes place). PERC and its breakdown products of TCE, cis-DCE, and VC are all present in the WAC plume. As shown in the figures, PERC and TCE concentrations in ground water above their RDCL of 5.0 ug/l are primarily confined to areas north of County Road 106. VC and cis-DCE concentrations above their respective ground water RDCLs of 2.0 ug/l and 70 ug/l have migrated south of County Road 106 into the residential subdivision.

The vertical extent of contamination was also investigated as part of this study and is graphically depicted in the geologic-cross sections provided in Figures 13-19 of the Investigation Report. Investigatory techniques utilized to evaluate the vertical extent of contamination across the Study Area included deep membrane interface probes (MIPs), monitoring wells (shallow, intermediate, and deeper), and deep continuous multichannel tubing (CMT) screening locations. As shown in the cross-sections, no contamination has been identified within the Study Area below depths of approximately 50-feet bsg.

The following tables outline constituents/parameters that were identified above RDCLs and/or IDCLs in soil and ground water samples collected across the Study Area:

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COCs IDENTIFIED IN <u>SOIL</u> SAMPLES ABOVE ACTION LEVELS						
сос	RDCL (ug/kg)	IDCL (ug/kg)	Highest Concentration in Soil (ug/kg)			
Tetrachloroethylene (PERC)	58	640	130,000			
Trichloroethylene (TCE)	57	350	6,100			
cis-1,2-Dichloroethylene (cis-DCE)	400	5,800	42,000			
Vinyl Chloride (VC)	13	27	91.5			
Methylene Chloride	23	1,800	270			
Xylene	170,000	170,000	2,700,000			
Ethylbenzene	13,000	160,000	680,000			
1,2,4-Trimethylbenzene (TMB)	2,500	170,000	1,000,000			
1,3,5-Trimethylbenzene (TMB)	610	68,000	470,000			
Isopropylbenzene (cumene)	11,000	42,000	120,000			
n-Propylbenzene	36,000	300,000	240,000			
Naphthalene	700	170,000	2,900			
TPH-GRO	25	300	13,000			
	mg/kg	mg/kg	mg/kg			
TPH-ERO	80	1,000	1,600			
THE LICO	mg/kg	mg/kg	mg/kg			

COCs IDENTIFIED IN GROUND WATER SAMPLES ABOVE ACTION LEVELS					
сос	RDCL (ug/l)	IDCL (ug/l)	Highest Concentration in Ground Water (ug/l)		
Tetrachloroethylene (PERC)	5.0	55	88,000		
Trichloroethylene (TCE)	5.0	31	10,200		
cis-1,2-Dichloroethylene (cis-DCE)	70	1,000	59,000		
Vinyl Chloride (VC)	2.0	4.0	3,390		
Methylene Chloride	5.0	380	.1		
1,1-Dichloroethylene	7.0	5,100	36.9		
Carbon Tetrachloride	5.0	22	9.8		
Xylene	10,000	20,000	250,000		
Toluene	1,000	8,200	1,400		
Ethylbenzene	700	10,000	67,000		
1,2,4-Trimethylbenzene (TMB)	16	5,100	130,000		
1,3,5-Trimethylbenzene (TMB)	16	5,100	47,000		
Isopropylbenzene (cumene)	830	10,000	6,000		
n-Propylbenzene	310	4,100	22,000		
Naphthalene	8.3	2,000	36		
Styrene	100	20,000	147		
Bis(2-ethylhexyl)phthalate	6.0	200	1,100		
Benzo(a)pyrene	0.2	0.39	0.50		
TPH-GRO	220	3,000	514,000		
TPH-ERO	100	1,100	57,000		

The locations with the highest concentrations were located within or very near the on-Site source areas. Other VOCs identified, but below RDCLs, include: trans-1,2-dichloroethylene (trans-DCE), 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethane (1,1-DCA), chloroethane, and chloroform. VOCs identified, but no IDEM default closure levels are available, include: sec-butylbenzene, tert-butylbenzene, p-isopropyltoluene, and dibromochloromethane. Other SVOCs identified, but below RDCLs, include: benzo(a)anthracene, benzo(b)flouranthene, benzo(k)flouranthene, anthracene, chrysene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, 2,4-dimethylphenol, 3&4-methylphenol, and butylbenzylphthalate. SVOCs identified, but no IDEM default closure levels are available, include: benzo(g,h,i)perylene, bis-(2-chlorethoxy)methane, and di-n-butylphthalate.

No significant concentration trends have been identified at the Site. The plume of contamination in the WAC appears to be at steady-state with concentrations of COCs remaining fairly constant over the past year (anywhere from 3 to 5 sampling events per well). Additionally, two (2) sampling

events conducted on residential private water wells (115 wells in June/July 2007 and 90 wells in August 2007) showed similar results. The EAC plume of contamination shows stable or slightly increased concentrations over the past year. Past and present monitoring well sampling results are summarized in Table 5 of the Investigation Report supplement.

C. Summary of Risks Associated with Site

Human, Ecological, & Environmental Risks

The contamination on-Site is located primarily in shallow and intermediate ground water zones. Shallow zones of ground water, located at depths between 5.0 to 15-feet bsg, and intermediate zones of ground water contamination, located at depths between 15 to 30-feet bsg, will most likely not impact wildlife or vegetation at the Site. Shallow soil contamination identified on-Site is primarily located beneath asphalt or concrete paved surfaces and should also not significantly impact ecologic receptors. Off-Site contamination is confined to intermediate zones of groundwater and deeper zones of ground water (deeper depths between 30 to 50-feet bsg). As such, wildlife and vegetation at off-Site locations should not be affected by the subsurface ground water contamination. Due to development, most of the Site and Study Area are devoid of suitable wildlife habitat. Negligible dermal absorption and inhalation exposure pathways exist at the Site during normal ground water sampling activities. These exposure pathways should be further minimized by the use of protective nitrile gloves and downwind positioning of sample bottles during filling. The installation of municipal water (combined with the abandonment of residential water wells) across the Study Area further negates potential contact with ground water.

Potential for Vapor Intrusion

Chlorinated solvent contamination has the potential to present inhalation hazards through vapor intrusion pathways. The pathways have to be complete for vapor intrusion to occur (i.e., shallow ground water contamination to soil/sub-slab vapors to indoor air). Since shallow ground water in the off-Site Study Areas is largely unaffected, the vapor intrusion pathway is not complete. COC concentrations in ground water samples collected from shallow monitoring wells and temporary wells installed straddling the water table in off-Site areas that are within 100-feet of buildings or residences are below screening levels listed in IDEM's DVIPP guidance document. Nonetheless, Geocel, at IDEM's request, conducted a vapor intrusion assessment at select residential properties. The results and conclusions of a vapor intrusion assessment were presented in a separate Vapor Intrusion Investigation - Meadow Farms Neighborhood report dated March 19, 2008 (a copy of this report is included as Supplement #4). The vapor intrusion sampling and analysis results indicated that the vapor intrusion pathway is not complete within the Study Area and further evaluation of subslab air and indoor air for vapor intrusion is not warranted in the Meadow Farms neighborhood unless conditions significantly change within the Study Area. Ground water samples collected from shallow monitoring wells located near buildings and residences will be evaluated against DVIPP guidance screening levels for at least four (4) quarters to evaluate if these conditions change (see Table 6 of Investigation Report – Supplement #2).

Impact of Current & Future Land-Use Issues

Indications are that future land uses will remain similar to current land uses (i.e., residential south of County Road 106 and industrial north of County Road 106). The remediation should not impact these land uses particularly since municipal water installations will be completed in the near future throughout the Study Area. Additionally, the residences that are connected to the municipal water supply have signed a "compact agreement" with the City of Elkhart that states they agree to have their well abandoned. Geocel's contractor has hired a licensed water well driller to complete the well abandonment activities at each residence. A copy of a signed compact agreement is provided in Appendix E.

D. <u>Background Concentration Assessment</u>

A detailed background concentration assessment is not warranted at the Site (statistical analysis, etc.). Of note is the potential in this aquifer system for background concentrations of TPH-ERO in soil and ground water. However, RES's experience indicates that background concentrations of TPH-ERO in ground water are generally less than 200 to 400 ug/l and these relatively low concentrations should not have a significant impact on stability monitoring activities. Monitoring wells MW-1D and MW-1s are current wells installed upgradient of the source zone in the WAC, while monitoring wells EMW-10D and EMW-10 are current wells installed upgradient of the source zone in the EAC. No VOC, SVOC, or TPH contaminants have been detected in these monitoring wells to date. However, 1,1,1-TCA was detected at a concentration of 20.4 ug/l in well TPW, which was installed near the EMW-10 wells as part of aquifer testing activities. Relatively low-level concentrations (i.e., below RISC RDCLs) of 1,1,1-TCA, 1,1-DCA, and chloroethane have been detected in EAC monitoring wells. Considering the detection of 1,1,1-TCA in well TPW, the possibility exists that these chlorinated ethanes may have migrated from an off-Site source. Concentrations of certain indicator parameters (dissolved oxygen, chloride, ethene, oxidation reduction potential, etc.) may also be collected from background wells to help evaluate remedial activities.

E. Additional Field Investigation Requirements

As described in Section 3.0 of the Investigation Report, the geologic and hydrogeologic information needed in relation to the anticipated remedial alternative has been adequately defined. Since no wildlife or vegetation should be affected by the contamination, Site-specific ecologic information is also adequately defined. Some additional parameters will be analyzed in ground water samples collected from remedial areas prior to and during remediation activities in order to document redox conditions of the aquifer and the progress of the remedial activities. Otherwise, normal quarterly ground water monitoring activities will continue in order to collect data for stability monitoring.

3.0 REMEDIATION PLAN

A. Evaluation of Remedial Alternatives

Remedial Technologies Evaluated & Rationale of Selection

Remedial options that were evaluated included:

- Classic pump & treat with air stripping and discharge/re-injection upgradient or to the municipal sewer system;
- Thermal desorption technologies in the source area;
- Soil vapor extraction (SVE)/air sparging (AS) systems;
- The addition of ozone to AS systems;
- Classic dig and haul scenarios for the immediate source areas;
- In-Situ Chemical Oxidation (ISCO); and
- Injection of Enhanced Bioremediation Materials (anaerobic and aerobic).

While all of these technologies are certainly viable options, many were dismissed due to logistical concerns and/or were determined to not be cost-effective to reach the ultimate remedial objectives at this Site (i.e., closure by stability monitoring). One of the primary evaluation criteria utilized was the ability of the remedial technology to ensure plume stability in the future. Therefore, source zone and near source zone remedial technologies that potentially removed the most contaminant mass in the shortest period of time were given highest priority. Community acceptance of the selected remedial technologies will likely be high considering minimal off-site disturbances will occur.

Pump & Treat Systems. Pump and treat systems tend to be effective only to a certain point resulting in good contaminant mass removal initially and greatly reduced contaminant mass removal thereafter. This limited long term effectiveness can lead to extended clean up times. Additionally, given the high transmissivity of the aquifer, a pump and treat system at the Site would likely require high volume pumping rates in different vertical zones to be adequately effective at this Site. Combined with the high iron content and hardness of the water which would tend to clog air stripping units and would require more intense maintenance and/or the addition of acid before stripping, this option was rejected.

Thermal Desorption. Thermal desorption remediation utilizes heat to volatilize contaminants in the subsurface. Hot air is pumped and/or a network of pipes that transmit heat are typically buried in the source zone. The vaporized contaminants are then usually collected and treated in some kind of secondary extraction system. Thermal desorption was dismissed due to its high initial costs, difficult construction conditions at the Site (not all source zone areas are conducive to extensive physical pipe/equipment installations), and certain vapor control issues due to the proximity of the primary source to the building.

Soil Vapor Extraction (SVE)/Air Sparging (AS). Soil vapor extraction (SVE) systems have been used at a wide variety of chlorinated solvent and petroleum hydrocarbon impacted sites across the country. Air sparging (AS) is often combined with SVE in order to volatilize shallow areas of ground water contamination. Due to the coarse-grained soils at the Site, SVE/AS systems would likely be a useful remedial technology. However, the relatively shallow water table across the Site would limit the SVE system to horizontally installed extraction wells. Large-scale SVE/AS systems (outside the source zone) were dismissed since the primary zone of contamination is below the water table off-Site. Therefore, a large-scale SVE/AS system was not technically feasible and large areas of piping installations would likely cause too much disruption to the normal course of business at the facility. A significant up-front capital expenditure would also be needed to install the large-scale SVE/AS systems. However, smaller scale, source zone area SVE/AS systems were considered a viable remedial option at the Site. SVE/AS systems constructed in each source zone would cause less disruption to business activities and could be performed with smaller, mobile equipment units. Horizontal extraction pipes could also be "jack-and-bored" underneath the building near the WAC source zone, thereby eliminating the need for significant construction activities inside the building. A relatively small-scale SVE/AS system under the building in the WAC would also help eliminate unsaturated soil contamination observed in this area. Much of the soil contamination observed under the building may be the result of vapors emanating from high concentrations of COCs in the ground water, which are trapped under the building and not necessarily from direct spills/releases. Operation and maintenance (O&M) costs of small-scale SVE/AS systems in both the WAC and EAC source zones would be minimized by short duration operations (i.e., 3 to 6 months). Treatment of contaminated vapors would entail carbon absorption technologies. Extracted and treated vapors would be frequently monitored in order to evaluate system performance. Due to the relatively coarse nature of the soils at the Site, it is anticipated that only a limited pilot study would be required to determine final system design and flow rates.

Ozone Addition. Ozone acts as a chemical oxidant that can help break-down the COCs at the Site (petroleum and chlorinated COCs). In a conventional AS system, air is pumped via smaller diameter pipes into shallow water table areas to help volatilize (and transmit) the contaminants to the vadose zone where the SVE system can ultimately extract the contaminated vapors. By adding ozone to the AS system, much of the contaminants in the shallow ground water are oxidized in-place. Ozone addition to the AS systems at the Site may be a viable option if system performance is lacking. Ozone can be generated on-Site and added at a later date, if necessary. In order to accommodate possible ozone addition, schedule 80 PVC pipe will be utilized for all AS system piping.

Source Zone Dig & Haul. Source zone dig and haul scenarios, were explored in detail. A major obstacle for this remedial option was that the soil and ground water removed from the Site would likely have to be disposed of as a "U-listed" hazardous waste based on the "derived from" rule, which greatly increased costs associated with this option. Additionally, disruption to business activities would be significant. Further, all areas of the source zone in the WAC could not be readily accessed for dig and haul activities due to building foundations or other impediments. Overall, the obstacles associated with dig and haul scenarios greatly outweighed the benefits.

In-Situ Chemical Oxidation (ISCO). In-situ chemical oxidation (ISCO) remediation breaks-down the contaminants to inert materials (i.e., salts, carbonic acid, water, carbon dioxide, etc.). A liquid chemical oxidant mixture is typically injected into the subsurface and/or applied within an open excavation. The primary limitation associated with ISCO is the ability of the injected oxidant materials to actually contact the areas of contamination. Treatment performance in highly stratified aquifers or finer-grained aquifers will likely be reduced since the oxidant material will not contact many areas of contamination. Conversely, ISCO remediation is typically most successful in relatively homogeneous, coarse-grained aquifers, as observed at the Site. Chemical oxidants will treat chlorinated solvents as well as petroleum hydrocarbons (as observed in the WAC). Treatment rates of 70 to over 90% have been achieved at similar sites (www.regenesis.com). Additionally, chemical oxidants are typically exhausted within approximately 3-weeks or sooner after application allowing for quick evaluation and timely re-applications, if needed. Access limitations and business disruptions would only include normal direct-push drill rig operations over a 5 to 7-day time period (depending on final injection grid design/spacings). Some source zone areas located beneath the inside of the southwestern portion of the Geocel building could still be accessed for injection by direct-push or other drilling methods. As such, ISCO technologies were considered a viable remedial alternative within primary source zones at the Site.

Enhanced Bioremediation Materials (EBMs). Enhanced bioremediation materials (EBMs) help stimulate bacteriological breakdown of the contaminants. They "enhance" the activity of the natural microbes already found in the subsurface. EBMs can be aerobic-based or anaerobic-based, both of which can be utilized for chlorinated solvent remediation (vinyl chloride tends to degrade more readily under aerobic conditions). Aerobic EBMs provide a controlled release of oxygen to the subsurface environment, while anaerobic EBMs provide a controlled release of hydrogen through lactic acid. The natural bacteria are then stimulated or "enhanced" by the release of these electron donors and, as a result, degrade the contaminants more rapidly. EBMs are typically injected using a direct-push drill rig directly into subsurface zones of contamination. Access limitations and business disruptions are only limited by normal drill rig operations. Another benefit with this technology is that both the horizontal extent and vertical extent of contaminated zones can be targeted. As with the ISCO applications, a primary limiting factor with injection of EBMs is distribution of the material within the targeted subsurface media. EBMs typically have excellent treatment rates within relatively homogenous, coarse-grained aquifers as observed at the Site. Therefore, injection of EBMs is considered a viable remedial alternative at the Site.

COBERTS ENVIRONMENTAL SERVICES ...

Summary of Conclusions for Each Technology

Technology	Cost- Effective	Access Limitations	Disruptive to Business	Geologically Conducive	Timely Results
Pump & Treat	No	Minor	Minor	Yes	No
Thermal Desorption	No	Yes	Yes/No	Yes	Yes
Large SVE/AS	No	Yes	Yes	Yes/No	Yes
Small SVE/AS	Yes	Minor	Minor	Yes	Yes
Ozone Addition	Yes	No	No	Yes	Yes
Dig & Haul	No	Yes	Yes	Yes	Yes
ISCO	Yes	Minor	Minor	Yes	Yes
EBMs	Yes	Minor	Minor	Yes	Yes

B. Selected Remediation Technologies

First and foremost, the primary potential receptor mitigation method is the extension of municipal water to the neighborhood area that has effectively eliminated potential receptors. Carbon filtration units were also provided to residences with raw water concentrations that exceeded 50% of the MCL prior to municipal water connections. These activities have already been performed in 2007/2008 and are detailed in Part E of this section.

Identification of Remedial Technologies to be Implemented

As shown in Figure 1, primary remediation activities will include:

- 1) Source zone in-situ chemical oxidation (ISCO);
- 2) Source zone SVE/AS systems;
- 3) Extended source area (on-Site) anaerobic enhanced bioremediation material (HRC®) injections;
- 4) Distal plume area anaerobic and aerobic enhanced bioremediation material (HRC*/ORC*) injections (north of County Road 106);
- 5) Stability monitoring (not depicted in figure).

As shown above, these specific remedial technologies are cost effective, geologically feasible, not highly disruptive, and typically produce timely results. The overall remediation approach expands outwardly in logical steps: primary source area ISCO injections to rapidly reduce elevated contaminant mass; source area SVE/AS systems (including under the building); extended source area HRC injections to further reduce on-Site contaminant mass; and off-Site distal plume area injections (HRC/ORC) to remediate high concentration areas that may not be a source, but may impact the ultimate stability of the plume. Each successive step effectively becomes a contingency for the preceding step. Lastly, multiple injection events are included as a contingency even though multiple events may not ultimately be necessary. Succeeding events will occur only after the results/effectiveness of the previous events are fully evaluated. Figure 2 shows a flowchart depicting the selected remedial technologies.

The aquifer conditions at the Site and the off-Site areas to be actively remediated are ideal for injection material remediation (i.e., remediation materials will actually contact a large percentage of the contaminated zones within the aquifer). As such, the ISCO applications have the potential to substantially reduce the high concentrations of COCs observed in the source zones. These treatments followed by SVE/AS and extended source zone HRC treatments could ultimately reduce contaminant concentrations by several orders of magnitude. The off-Site HRC/ORC treatment areas will also help with certain zones of relatively high off-Site contamination that may not be a source, but could still affect the stability of the plume. The overall goal of the remediation is to stabilize and/or shrink the plume, not to remediate the entire plume to concentrations below cleanup levels.

Need for Risk Assessment

IDEM RISC default closure levels coupled with plume stability monitoring will be used as the ultimate cleanup objectives. As such, since potential receptor mitigation activities (i.e., extension of municipal water to potential receptors) are currently taking place within the Study Area, no formal risk assessment is needed.

Detailed Description of Selected Remedial Technologies

In-Situ Chemical Oxidation (ISCO). As previously stated, the aquifer conditions at the Site and the off-Site areas to be actively remediated are ideal for injection material remediation. The ISCO injection materials utilized at the Site will consist of RegenOxTM, which is manufactured by Regenesis. Product information sheets and several technical bulletins detailing the RegenOx product are provided in Appendix A. RegenOx is a "solid alkaline oxidant that employs a sodium percarbonate complex with a multi-part catalytic formula". The materials can be injected into subsurface contaminant zones utilizing standard direct-push drill-rig equipment and a pump. "Once in the subsurface, the combined product produces an effective oxidation reaction comparable to that of Fenton's Reagent without a violent exothermic reaction". The ISCO materials and contaminants react to form salts, water, carbon dioxide, and weak acids. Up to three (3) successive ISCO treatments may be utilized as a contingency. No state or federal permit applications or waste disposal approvals will be necessary. Baseline contaminant concentrations and indicator parameter concentrations (i.e., DO, ORP, pH, etc.) will be collected at key monitoring well locations before ISCO applications and every two (2) weeks after injections to help evaluate the effectiveness of each The oxidizing capacity of the RegenOx product is typically diminished after approximately three (3) to four (4) weeks after injection allowing for timely evaluation and reinjections, if needed.

The ISCO applications will be performed in on-Site source zones from depths of approximately 5.0 to 20 feet bsg. Preliminary design estimates by Regenesis technical staff indicate approximately 100 injections points over a 12,000 square feet area in the WAC and approximately 25 injection points over a 2,200 square feet area in the EAC. Approximately 79,050 pounds of RegenOx total over three (3) events will be injected in the WAC source zone, while approximately 9,900 pounds of RegenOx total over three (3) injection events will be injected in the EAC source zone. As some utilities, walls, and other structures are included in the treatment zones, the actual pounds per foot will be calculated

once the final number of points are determined, but it is anticipated that the total amount of material injected will be similar to the recommended Regenesis estimate on lbs/ft injection rates.

Anaerobic Enhanced Bioremediation Materials (HRC®). Anaerobic enhanced bioremediation material (EBM) injections will also occur in extended zones of on-Site source areas and specific off-Site areas located in the WAC (see Figure 1). Anaerobic EBMs utilized at the Site will consist of HRC® Advanced (or 3DMicroEmulsion – 3DMe®), which is manufactured by Regenesis. Product information sheets and several technical bulletins detailing the HRC product are provided in Appendix B. "When injected into contaminated soil and groundwater, HRC Advanced produces a sequential, staged release of its electron donor components. The immediately available free lactic acid is fermented rapidly while the controlled-release lactic acid is metabolized at a more controlled, more gradual rate. The fatty acids are converted to hydrogen over a mid to long range timeline giving HRC Advanced an exceptionally long electron donor release profile. This staged fermentation provides an immediate, midrange and very long term, controlled-release supply of hydrogen (electron donor) to fuel the reductive dechlorination process." The longevity of the HRC in the subsurface ranges from 2.0 to 5.0 years. The materials can be injected into subsurface contaminant zones utilizing standard direct-push equipment and a pump. No state or federal permit applications or waste disposal approvals will be necessary. Baseline contaminant concentrations and indicator parameter concentrations (i.e., DO, ORP, pH, etc.) will be collected at key monitoring well locations before HRC applications and after injections following normal quarterly monitoring procedures to help evaluate the effectiveness of each injection.

Up to three (3) consecutive HRC injections will be utilized in the on-Site WAC and EAC. The on-Site WAC HRC treatment area is approximately 37,000 square feet, while the on-Site EAC HRC treatment area is approximately 17,600 square feet. Treatment zones for on-Site HRC will also be in the 5-20 feet range. The estimated amount of HRC in the on-Site WAC is 167,640 pounds of microemulsion (15,240 lbs of HRC) and estimated amount of HRC in the on-Site EAC is 74,910 pounds of microemulsion (6,810 lbs of HRC). The number of anticipated injection points in the on-Site WAC is 136 per event, while injection points in the on-Site EAC are anticipated to be 72 per event. The final injection rates will be calculated based on the actual number of points, but will be similar to injection rates recommended by Regenesis.

One (1) HRC injection each will be utilized in distal plume areas located at intermediate depths and deeper depths in the off-Site WAC (see Figure 1). The off-Site intermediate depth WAC HRC treatment area is approximately 40,000 square feet, with a treatment zone depth in the 15 to 30 feet range. The estimated amount of HRC in the off-Site intermediate depth WAC is 167,640 pounds of microemulsion (15,240 lbs of HRC). The off-Site deeper depth WAC HRC treatment area is approximately 20,000 square feet, with a treatment zone depth in the 40 to 50 feet range. The estimated amount of HRC in the off-Site deeper depth WAC is 74,910 pounds of microemulsion (6,810 lbs of HRC). The number of anticipated injection points in these areas will be determined in the future and will follow Regenesis estimates/recommendations based on concentrations identified within the aquifer at the time of treatment.

Aerobic Enhanced Bioremediation Materials (ORC®). Aerobic enhanced bioremediation material (EBM) injections will also occur in specific off-Site areas located in the WAC (see Figure 1). Aerobic EBMs utilized at the Site will consist of ORC® Advanced, which is manufactured by Regenesis. Product information sheets and several technical bulletins detailing the ORC® product are provided in Appendix C. Aerobic EBMs have been successfully utilized to treat vinyl chloride, which may remain recalcitrant after HRC treatments. ORC injections will likely occur in the same areas as the off-Site HRC treatments or they may not occur at all depending on the vinyl chloride concentrations observed after the HRC treatments. Multiple ORC injections may be utilized to treat the vinyl chloride accumulations. The number of anticipated injection points in the potential ORC injection areas will be determined in the future and will follow Regenesis estimates/recommendations based on concentrations identified within the aquifer at the time of treatment.

Soil Vapor Extraction/Air Sparging (SVE/AS). SVE/AS systems are also proposed as part of the source zone remediation plan at the Site. A diagram of a typical SVE/AS system setup and case studies illustrating the effectiveness of SVE/AS systems are provided in Appendix D. Figure 1 shows the proposed location of the two (2) SVE/AS remediation system locations. The first would be located in the WAC beneath the southwest corner of the Geocel facility building and in the area of the former UST systems. The second location is in the EAC at the southeast corner of the facility in the area centered around boring GP-40. These areas have near surface contamination in course sandy soils and lend themselves to efficient SVE/AS remediation.

The SVE/AS treatment systems consist of the following components:

- 1) Air filter and regenerative blower to direct air at less than 15 psi to the SVE/AS Sparge Header and horizontal wells.
- 2) SVE Extraction Wells. These are horizontal wells with screen fittings located above the contaminated zone located to collect vapors generated from the sparge wells.
- 3) An Air/Water separator on the Extraction Well header that will collect and condense water vapor generated in the Extraction Wells.
- 4) A low pressure/high volume regenerative blower.
- 5) Activated Carbon Adsorption.
- 6) System Control Panel.

In both areas the SVE wells shall be horizontal systems installed with conventional jack-and-bore drilling systems. The AS wells may be horizontal or vertical installations. Well placement and spacing shall be determined following on-site pilot studies that will be used to determine the site-specific migration of vapors through the soil. Air injected into the aquifer typically migrates in channels as opposed to direct air scrubbing by means of air bubbles in the groundwater. The zone of influence of a sparge header can vary from a radius of 5 feet to 30 feet based on 2" headers and soil conditions. The limited pilot study will determine the optimum zone of influence for this site. Due to the relatively coarse nature of the soils, adequate air movement is expected to occur in these areas. Horizontal wells in coarse soils typically have a greater zone of influence than vertical wells.

Sparge and extraction well manifolds shall be constructed of continuous cast, 2" high density polyethylene (HDPE) pipe. HDPE pipe has better shatter resistance and is capable of withstanding higher temperatures than PVC or CPVC pipe. In order to improve system efficiency a filter will be installed on the air intake blower to prevent airborne particles from damaging the blower or header system. Check valves will be installed to prevent transient high pressure in the screened sections of the sparge and extractions systems from forcing groundwater back into the manifolds during system shutdown.

Wells will be equipped with throttling valves to allow system balancing and pulsing during operation. Pulsing the system (short duration on/off events for each well) helps prevent the occurrence of preferential flow paths in the subsurface. Solenoid valves on each well will be cycled periodically to allow cycling during the vapor extraction process. Experience has shown that wells that are cycled can have improved extraction efficiency over continuously operated wells.

Each well will be fitted with a sample port to allow attachment of a flow meter and pressure gauge used to balance the system. Each manifold system will also be fitted with a permanent pressure gauge to allow for better system control/management. All manifolds shall have automatic pressure relief valves to prevent damage to the wells and headers. Once the optimum air sparge rate has been determined by pilot trials, the full-scale system shall be installed. The air injection to air extraction ratio shall be maintained at 1 to 4.

During operation the SVE/AS system will be monitored for the following parameters to assure efficient extraction of VOCs.

- 1) Groundwater DO and VOCs.
- 2) VOCs in the extracted air.
- 3) Airflow in the sparge and extraction headers.
- 4) Sparge pressure and extraction vacuum.
- 5) Aquifer water levels.
- 6) VOC discharge from the activated carbon system.

Operational data will be maintained in the Operational Log to be kept on-Site. It is anticipated that no air permitting will be necessary since outflow air will be treated through carbon adsorption. As indicated above, outflow air will be periodically monitored.

C. Monitoring & Sampling Plan

The primary monitoring activities will include quarterly ground water sampling and analysis from existing monitoring wells across the Study Area. Currently, 119 monitoring wells have been installed across the Study Area, including 39 on-Site wells and 80 off-Site wells. Adequately located point of compliance (POC) wells exist along the western, eastern, and southern edges of the Impacted Area. Background wells that have consistently shown no detections of COCs are also located upgradient of the WAC and EAC plumes (excepting 1,1,1-Trichloroethane recently detected at a concentration of 20.4 ug/l in a sample collected from well TPW, which is located in a

background position relative to the EAC plume). Six (6) sentinel wells (MW-41i, MW-41D48, MW-46i, MW-46D48, MW-47i, and MW-47D49) have been installed downgradient of the Impacted Area and have shown no detections of COCs.

Sampling Plan Details & Data Management

Primary sampling and monitoring parameters will consist of the analysis of full list VOCs utilizing EPA Method 8260. On-Site monitoring wells and select off-Site monitoring wells near the Site, will also be analyzed for TPH-GRO, TPH-ERO, and full SVOCs (including cPAHs). Select indicator parameters, including but not limited to, dissolved oxygen (DO), chloride, ethane, oxidation reduction potential (ORP), pH, and others may also be analyzed at specific monitoring wells on an as needed basis. Select monitoring wells will be sampled on a quarterly basis at least for the initial eight (8) quarters. The initial eight (8) quarters of monitoring well data will provide the basis for background data used in plume stability monitoring statistical calculations. After the initial eight (8) quarters of data are evaluated, a lesser number of monitoring wells will be selected for continued quarterly monitoring (possibly 50 to 60 monitoring wells). The monitoring wells selected for continued quarterly monitoring will be located at points that provide adequate data for continued evaluation of plume stability (i.e., background wells, point of compliance wells, sentinel wells, messenger wells, and key area of concern wells located within the Impacted Area).

At a minimum, quarterly progress reports will be submitted to IDEM for review and evaluation following the format described in the IDEM RISC Users Guidance. Maps, tables, statistical evaluation data, and graphical depictions of the data over time will be presented in the progress reports. Statistical evaluations will include the use of Mann-Kendall trend tests and will follow the stability monitoring procedures described in Appendix 3 of the IDEM RISC Technical Guidance. A flow chart from the RISC Technical Guidance document describing the stability monitoring process is provided in Appendix E. A completion report will be submitted after adequate plume stability is documented across the Study Area.

D. Projected Work Schedule

Implementation of the Remediation Work Plan has already begun across the Study Area. Primary activities include the current installation of municipal water at approximately 100 residences south of County Road 106, which is expected to be complete in October 2008. Quarterly monitoring activities have also been implemented across the Study Area. Many of the monitoring wells have already been sampled for four (4) quarters (see Table 5 in the Investigation Report). Additionally, much of the community relations activities, described in the CRP included in Supplement #3, have been completed. As shown in the flowchart included as Figure 2, each successive remedial activity after source zone remedial activities are interdependent on the results of the previous step. As an example, if source area remedial activities (ISCO and SVE) significantly reduce contaminant concentrations in on-Site source areas, multiple anaerobic EBM injections (HRC) may not be needed at the Site. Implementation of proposed remedial activities outside the on-Site source areas will only occur after adequate evaluation of plume stability across the Study Area.

Projected Installation & Startup

As previously discussed, quarterly ground water monitoring is ongoing across the Study Area and municipal water installations are currently being implemented. At this time, it is anticipated that source area remedial activities (ISCO and/or SVE) will begin in 2009 (depending on review, public notice, and approval of the workplan). Proposed remedial activities outside of on-Site source areas will only be initiated as needed after evaluation of plume stability across the Study Area.

Contaminant Removal & Treatment Rates

Source area remediation activities could result in significant contaminant treatment rates (70% to 90%) and the conditions at the Site are optimal for ISCO and SVE applications. Air flow within unsaturated soils will likely be adequate to remove large percentage of contaminants given the sandy nature of the soils at the Site. Both ISCO and SVE remedial applications have been successful at numerous facilities across the United States under similar conditions. Primary remediation progress milestones will be evaluated based on plume stability monitoring activities. Presently, the relatively high concentrations of contaminants in the on-Site source areas have the potential to contribute to some plume expansion over time. As such, the proposed aggressive source area remedial activities will likely have a significant documentable impact on plume stability. At a minimum (as shown in the flowchart in Appendix E), limited ground water monitoring will continue for at least six (6) to seven (7) more years. Depending on the success of the remedial activities and the results of the stability monitoring, ground water monitoring may continue for more than seven (7) years.

Operation & Maintenance Plan

The primary remedial activity that will require an active operation and maintenance (O&M) plan will be the proposed SVE/AS systems installed at the Site. At this time, it is anticipated that the SVE/AS systems will be active for only three (3) to six (6) months. Primary O&M activities associated with the SVE/AS systems will include weekly equipment checks, sampling and disposal of condensate water, sampling and analysis of outflow air, and other miscellaneous maintenance tasks (as previously mentioned in Part B of this Section). Upon initial SVE/AS system startup these O&M tasks will be completed on a daily basis.

O&M related activities associated with the ISCO applications and EBM injections will simply consist of sampling select monitoring wells within and near the treatment areas for specific indicator parameters and the COCs in order to document the effectiveness of the injections. These indicator wells may be sampled weekly with the ISCO injections and monthly (as needed) with the EBM injections.

Contingency planning is built-in to the proposed remedial plan. As an example, multiple injection events may be needed to adequately reduce contaminant concentrations. Up to three (3) ISCO applications are proposed for the on-Site source areas, if needed. Since the contaminant mass typically responds to the ISCO applications in three (3) to four (4) weeks, all three (3) injections may be applied within a relatively short period of time to help ensure their effectiveness. After initial SVE/AS system startup, some system modifications may need to be performed and will likely consist

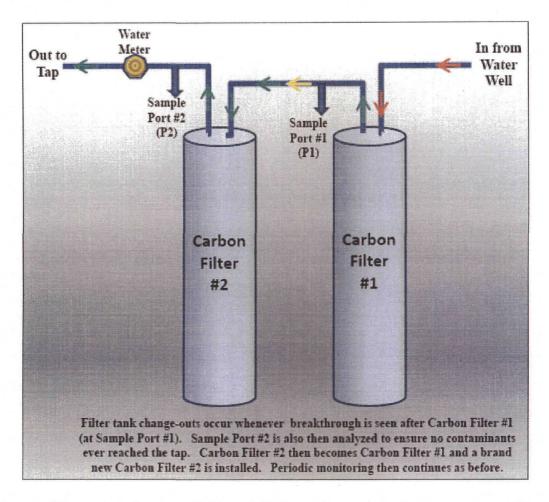
of raising or lowering vacuum levels. If the AS portion of the system is activated, sparge points will be pulsed (i.e., one point is on while the other is off) to help prevent "pushing" of the plume and the creation of preferential flowpaths. On-Site personnel employed by Geocel will also be enlisted to notify if the system shuts down or fails.

E. Potential Receptor Mitigation Activities

As previously mentioned, potential receptor mitigation activities have taken place since the discovery of contamination within the residential neighborhood south of County Road 106 in June 2007. These activities have included the following:

- The continual supply of bottled drinking water to 115 residential homes located south of County Road 106;
- The installation and maintenance of GAC filtration systems in twenty-five (25) homes with detections of VOCs greater than 50% of the U.S.EPA MCL. Detections primarily consisted of vinyl chloride at levels greater than or equal to 1.0 ug/l; and
- The installation/connection of municipal water to approximately 100 homes located south of County Road 106 has been initiated by Geocel. These project activities started in July 2008 and are scheduled for completion in October 2008. Bottled water supplies and GAC filters will be discontinued after municipal water connections are completed.

As depicted in Figure 7 of the Investigation Report, approximately 100 homes will be connected to municipal water in the near future. Figure 3 depicts the locations of the twenty-five (25) residences that received dual-tank carbon filtration units. These residences also received a continual supply of bottled drinking water provided by Geocel. The diagram below depicts a typical installation set-up within the home and how filtration tank change-outs occurred at each residence.



Sample ports P1, located after the tank #1, and P2, located after tank #2, where periodically sampled at each residence (every 2 to 4 weeks depending on contaminant mass and water usage rates). Water usage rates versus contaminant mass in the raw water were tracked in order to estimate potential breakthrough times. At least one (1) filter tank change-out occurred at most of the twenty-five (25) residences. As expected, residences with the highest raw water concentrations and usage rates required multiple filter tank change-outs. As an example, the residence located at 53572 Kershner Lane with the highest total contaminant mass has had three (3) filter tank #1 change-outs to date. Presently, no detections of VOCs have ever occurred at the P2 sample port, which indicates no breakthrough of contaminants have occurred to the resident's ultimate point-of-use. The dual tank filtration systems were designed specifically for this type of conservative redundancy. The filtration units and bottled drinking water will be discontinued after the municipal water installations are completed in the near future. Laboratory analysis was always performed on a "Rush" basis in order to effectively evaluate the status of each system within a timely manner. Filtration system analytical reports documenting these monitoring activities are provided on the DVD-ROM included in Appendix D of the Investigation Report.

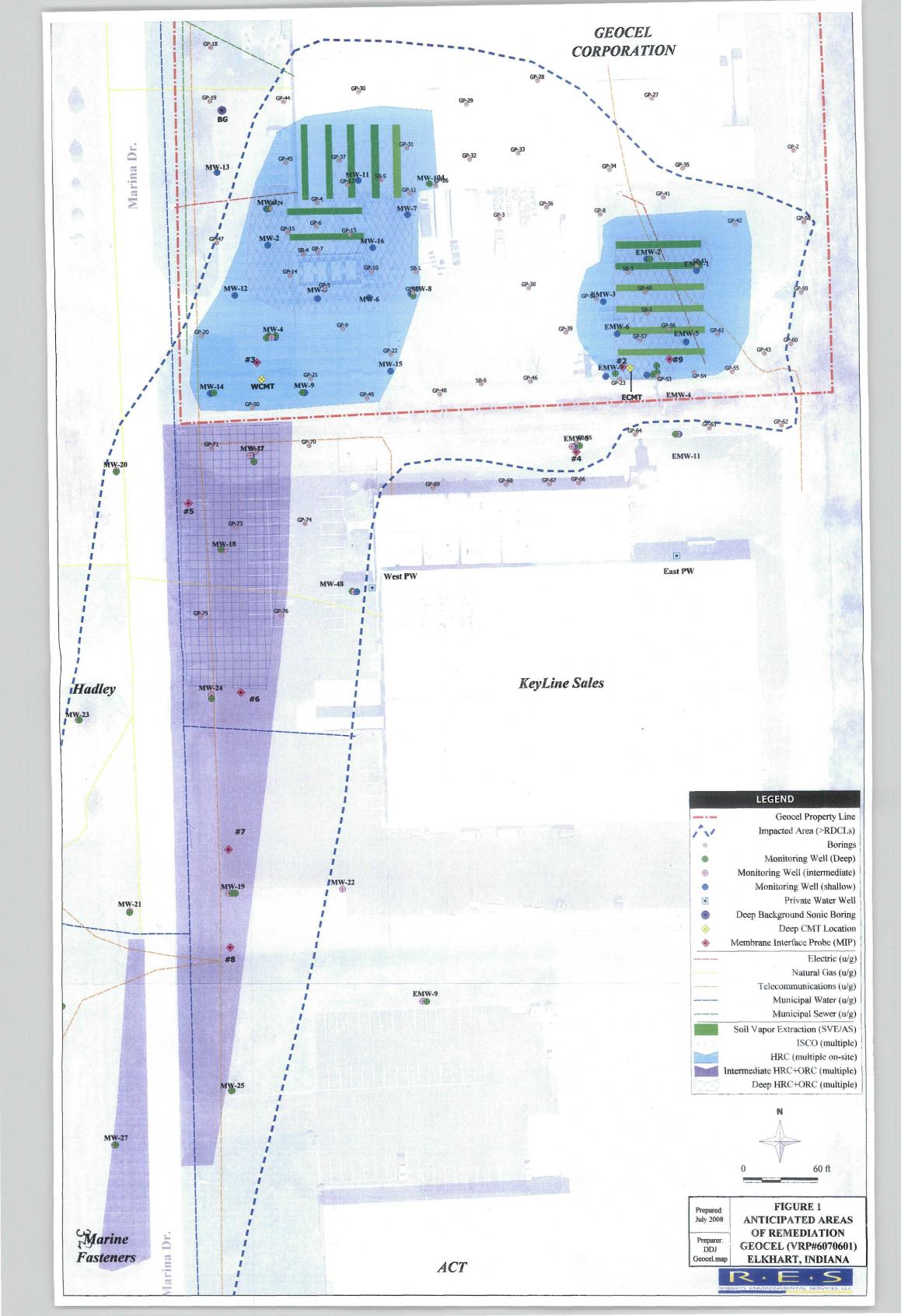
4.0 REFERENCES

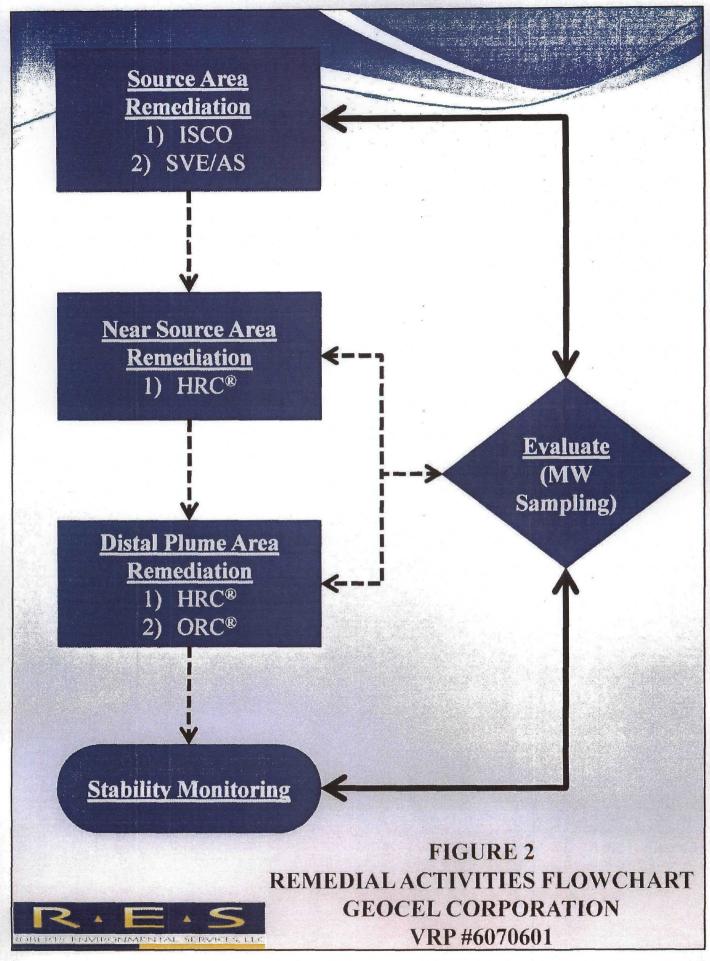
- FRTR Federal Remediation Technologies Roundtable. Remediation Technologies Screening Matrix & Reference Guide, Version 4.0 (http://www.frtr.gov/matix2/top_page.html)
- FRTR, 1995, Abstracts of Remediation Case Studies, Volume 1, Federal Remediation Technologies Roundtable (Member Agencies).

See Section 5.0 of the Investigation Report for Complete References used in this Report

FIGURES

.....







APPENDIX A

ISCO Materials (RegenOxTM)
[Double-sided documents]





CHEMICAL OXIDATION REDEFINED...

RegenOx™ is an advanced in situ chemical oxidation technology* designed to treat organic contaminants including high concentration source areas in the saturated and vadose zones

PRODUCT FEATURES:

- Rapid and sustained oxidation of target compounds
- Easily applied with readily available equipment
- Destroys a broad range of contaminants
- More efficient than other solid oxidants
- Enhances subsequent bioremediation
- Avoids detrimental impacts to groundwater aquifers



RegenOx product application

HOW IT WORKS:

RegenOx maximizes in situ performance using a solid alkaline oxidant that employs a sodium percarbonate complex with a multi-part catalytic formula. The product is delivered as two parts that are combined and injected into the subsurface using common drilling or direct-push equipment. Once in the subsurface, the combined product produces an effective oxidation reaction comparable to that of Fenton's Reagent without a violent exothermic reaction. RegenOx safely, effectively and rapidly destroys a wide range of contaminants in both soil and groundwater (Table 1).

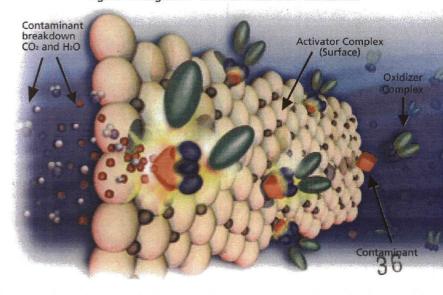
ACHIEVES RAPID OXIDATION VIA A NUMBER OF MECHANISMS

RegenOx directly oxidizes contaminants while its unique catalytic complex generates a suite of highly charged, oxidative free radicals that are responsible for the rapid destruction of contaminants. The mechanisms by which RegenOx operates are:

- Surface- Mediated Oxidation: (see Figure 1 and description below)
- Direct Oxidation: C₂Cl₄ + 2 Na₂CO₃ 3 H₂O₂ + 2 H₂O ←→ 2CO₂ + 4 NaCl + 4 H₂O + 2 H₂CO₃
- Free Radical Oxidation:
 - Perhydroxyl Radical (HO2 •)
 - Hydroxyl Radical (OH•)
 - Superoxide Radical (O2*)

Figure 1. Surface-Mediated Oxidation is responsible for the majority of RegenOx contaminant destruction. This process takes place in two stages. First, the RegenOx activator complex coats the subsurface. Second, the oxidizer complex and contaminant react with the activator complex surface destroying the contaminant.





^{*} Patent applied for



From Mass Reduction to Bioremediation:

RegenOx[™] is an effective and rapid contaminant mass reduction technology. A single injection will remove significant amounts of target contaminants from the subsurface. Strategies employing multiple Regenox injections coupled with follow-on accelerated bioremediation can be used to treat highly contaminated sites to regulatory closure. In fact, RegenOx was designed specifically to allow for a seamless transition to low-cost accelerated bioremediation using any of Regenesis controlled release compounds.

Significant Longevity:

RegenOx has been shown to destroy contaminants for periods of up to one month.

Product Application Made Safe and Easy:

RegenOx produces minimal heat and as with all oxidants proper health and safety procedures must be followed. The necessary safety guidance accompanies all shipments of RegenOx and additional resources are available on request. Through the use of readily available, highly mobile, direct-push equipment and an array of pumps, RegenOx has been designed to be as easy to install as other Regenesis products like ORC® and HRC®.

Effective on a Wide Range of Contaminants:

RegenOx has been rigorously tested in both the laboratory and the field on petroleum hydrocarbons (aliphatics and aromatics), gasoline oxygenates (e.g., MTBE and TAME), polyaromatic hydrocarbons (e.g., naphthalene and phenanthrene) and chlorinated hydrocarbons (e.g., PCE, TCE, TCA).

Oxidant Effectiveness vs. Contaminant Type:

Table 1								
Contaminant	RegenOx™	Fenton's Reagent	Permanganate	Persulfate	Activated Persulfate	Ozone		
Petroleum Hydrocarbons	Α	A	В	В	В	Α		
Benzene	Α	Α	D	В	В	A		
MTBE	Α	В	В	С	В	В		
Phenols	Α	Α	В	С	В	Α		
Chlorinated Ethenes (PCE, TCE, DCE, VC)	Α	Α	A	В	Α	A		
Chlorinated Ethanes (TCA, DCA)	Α	В	С	D	C	В		
Polycyclic Aromatic Hydrocarbons (PAHs)	Α	Α	В	В	Α	Α		
Polychlorinated Biphenyls (PCBs)	В	С	D	D	D	В		
Explosives (RDX, HMX)	Α	Α	A	Α	A	A		

Based on laboratory kinetic data, thermodynamic calculations, and literature reports.

Oxidant Effectiveness Kev:

- A = Short half life, low free energy (most energetically favored), most complete
- ${\bf B} = {\bf Intermediate\ half\ life,\ low\ free\ energy,\ intermediate\ degree\ of\ completion}$
- C = Intermediate half life, intermediate free energy, low degree of completion
- D = Long half life, high free energy (least favored), very low degree of completion



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Advanced Chemical Oxidation

Thermodynamics and Kinetics

To understand the complete oxidation picture, one must also consider the thermodynamics and the kinetics of the reaction. Thermodynamics tells us the likelihood or potential that a reaction will take place and kinetics tells us how fast it will happen.

Thermodynamics

Voltages are commonly used when comparing chemical oxidants; however, they are typically derived from hydrogen oxidation half-cell reactions, which are both inaccurate (we are not interested in oxidizing hydrogen to water) and incomplete. When interpreting completely balanced equations in terms of the thermodynamics, the relative Gibb's Free Energy is a more valid approach for comparing reactions than voltages based on half-cell reactions alone. Gibb's Free Energy and voltage are linked by the following equation, where E is the voltage, n is the number of electron-equivalents per mole and F is Faraday's constant:

$$E = \frac{-\Delta G}{nF}$$

In Table 1 below, we present data for the comparative oxidation of PCE (C_2Cl_4) rather than hydrogen and use Gibbs Free Energy (ΔG) as a measure of the energy that is available from the reaction. The lower the free energy, the more negative the ΔG and the more likely the reaction will occur. When compared with three other chemical oxidation products in Table 1, RegenOx (which runs under basic conditions) yields the lowest free energy (and highest voltage). This means that the RegenOx reaction is the most favorable oxidation reaction.

Table 1. Comparitive Oxidation of PCE

Chemical Oxidant	Balanced Equation	Gibbs Free Energy (ΔG)
RegenOx TM	$C_2Cl_4 + 2 H_2O_2 + 4 NaOH \Leftrightarrow 2 CO_2 + 4 NaCl + 4 H_2O$	-338 kcal/mol
Potassium Permanganate	$C_2Cl_4 + 4 \text{ KMnO}_4 \Leftrightarrow 2 \text{ CO}_2 + 4 \text{ MnO}_2 + 4 \text{ KCl} + 2 \text{ O}_2$	-329 kcal/mol
Potassium Persulfate	$C_2CI_4 + 2 K_2S_2O_8 + 4 H_2O \Leftrightarrow 2 CO_2 + 4 KCI + 4 H_2SO_4$	-271 kcal/mol
Hydrogen Peroxide	$C_2Cl_4 + 2 H_2O_2 \Leftrightarrow 2 CO_2 + 4 HCl$	-261 kcal/mol

Kinetics

The oxidation rates of toluene and PCE were compared (by using average pseudo-first order rate coefficients as measured in laboratory studies) with RegenOx and permanganate. Toluene was most quickly oxidized by RegenOx (Figure 1). RegenOx oxidized PCE at a similar rate as permanganate (Figure 2). RegenOx oxidation is kinetically favorable with a range of environmental contaminants, including chlorinated aliphatics such as PCE and hydrocarbons such as toluene.

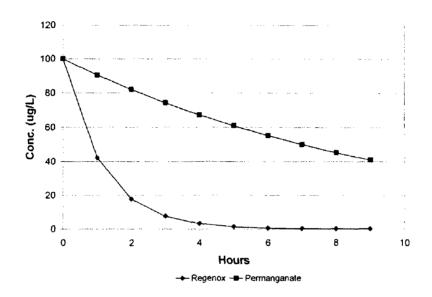


Figure 1. Comparison of Toluene Oxidation

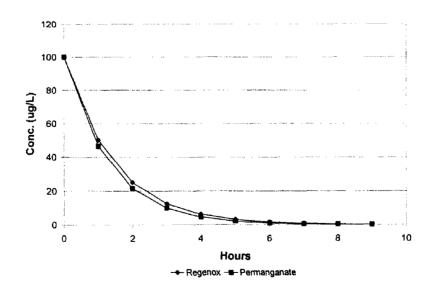


Figure 2. Comparison of PCE Oxidation

Advanced Chemical Oxidation

Groundwater Temperature and Pressure after Application

RegenOxTM uses a solid alkaline oxidant with sodium percarbonate as the main active ingredient. The product is delivered as two parts that are combined and injected into the subsurface using common drilling or direct-push equipment. Once in the subsurface, the combined product produces and effective oxidation reaction comparable to that of Fenton's reagent, yet without a violent exothermic hazard. As a result of this reaction RegenOx safely, effectively and rapidly destroys a wide range of contaminants in both soil and groundwater.

Considering a Fenton's-type treatment, all the hydrogen peroxide is immediately available for reaction. In its infancy, Fenton's-type oxidations were applied using hydrogen peroxide concentrations as high as 30%. More recently, concentrations are typically lower at or near 16% hydrogen peroxide. Regardless of the percentage, the hydrogen peroxide is immediately available to react causing extreme temperature and pressure increases. Because of the Arrenhius response to temperature, the reactions rates increase and as a result, large temperature and pressure increases can often be measured (Figure 1). One liter of a 16% hydrogen peroxide solution can produce 300 liters of vapor instantaneously under typical Fenton's-Type reaction conditions.

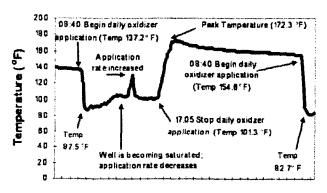


Figure 1. Fenton's Reagent Temperature Effects

In contrast, RegenOx is typically applied as an 8% solution which is approximately 3% bounded-hydrogen peroxide. Under RegenOx reaction conditions, the hydrogen peroxide becomes available for reaction as it is slowly released in a controlled manner from the carbonate ion. In field application, RegenOx produces a mild exothermic reaction that may result in a gradual temperature increase over 5-10 days. Groundwater temperatures typically return to ambient levels after 10-20 days (Figures 2 and 3). Both temperature profiles were at sites in which approximately 1000 pounds of oxidant was delivered as a 12% solution over a 2 day injection period. The overall temperature increase has not been observed to exceed approximately 5 degrees Celsius (8 degrees Fahrenheit). Increased pressures have only been observe during the injection event as a function of physical injection pressure and

localized groundwater mounding and/or short-circuiting. Some oxygen gas may be produced during RegenOx injections, however the amount is much less than a comparable Fenton's application.

Thus, observation of RegenOx application in the field demonstrates that it does not produce violent exothermic reactions that are commonly associated with other Fenton-type chemical oxidation applications and therefore is considered a safer subsurface contaminant oxidant.

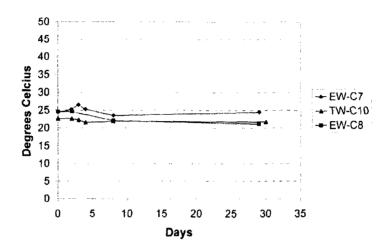


Figure 2. Temperature at Georgia Beta Test Site

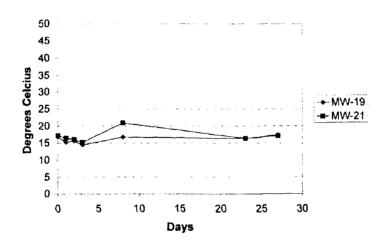


Figure 3. Temperature at Vermont Beta Test Site

Advanced Chemical Oxidation

Excavation Application

Purpose: Describe the preferred protocol for excavation application of RegenOx.

RegenOxTM is a specialty, groundwater and/or soil remediation product designed to chemically oxidize contaminants upon contact. It is a separately packaged, two-part product consisting of Part-A (the oxidizer complex powder) and Part-B (the activator complex gel). Each part is delivered in easy to handle pails. Part-A and Part-B can be readily mixed together without concern for excess heat or gas generation. RegenOx does not require special injection tools or patented injection processes. For source area contaminant treatment in the saturated zone, RegenOx is typically injected into the subsurface using standard application equipment readily available to the remediation contracting and drilling industry. When treating source area contamination in the vadose zone, RegenOx can be used in conjunction with an excavation removal treatment. The material can be easily applied into an excavation pit to extend source contamination removal from the saturated zone and laterally from the excavation walls into the vadose zone.

First, all personnel within the exclusion zone of the excavation application should have proper Personal Protection Equipment (PPE; Figure 1*). They should have PPE to protect the eyes, respiratory system and skin. Second, the recommended dose of RegenOx Part B activator gel should be re-suspended/mixed in the shipping container (Figure 1) and then applied to the excavation pit. The Part B should be distributed evenly and mixed into the soil as well as possible. Care should be taken not to splash the product out of the pit or on personnel. Third, the recommended dose of Part A oxidizer powder should be applied to the excavation pit. The Part A should be distributed evenly and mixed into the soil. Care should be taken to avoid fugitive dust emissions or depositing on personnel. Fourth, once Part A and B are applied to the excavation, water should be added to the treatment area until standing (saturated), this will enhance the distribution of the RegenOx material. As a final step, clean backfill can be added to the excavation pit.

Photos from a RegenOx excavation application are shown on the following page. RegenOx was added to the pit by using a front end loader (Figure 2) and the excavation was filled with clean backfill (Figure 3).



Figure 1: Proper PPE for RegenOx handling and application.

*All photos courtesy of URS of North Carolina





Figure 2: Application of RegenOx with a Front End Loader.







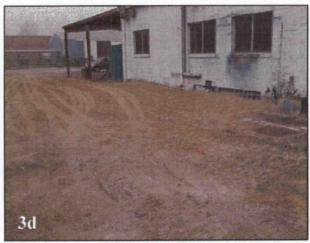


Figure 3: Photo Documentation of a RegenOx Excavation Application.

3(a) the open excavation pit, (b) adding RegenOx with the front end loader, (c) backfilling with clean soil, (d) the site after backfilling is complete

Regenox TECHNICAL BULLETIN 4.0

RegenOxTM

Advanced Chemical Oxidation

Compatibility with Underground Storage Structures and Pipes

The use of RegenOxTM in proximity to underground tanks and pipes is not a concern. Underground tanks and pipes are installed to meet the relatively corrosive conditions of wet soil. Also, the advent of Fiberglass Reinforced Plastics (FRPs) has greatly diminished the overall concerns in this area. Both metal and FRP installations are normally exposed to fairly wide ranges of pH, oxygen saturated water and even corrosive mineral contents. The biggest threat to system failure lies in poor installation and not in the presence of materials such as RegenOx.

Interactions with metals and plastics are an extremely complicated phenomenon that is dependent on time, temperature and concentrations. Given enough time, oxidizers and caustic solutions will slowly react with certain metals and plastics. RegenOx has a high oxidizing potential and a high pH; however, RegenOx is relatively short-lived in the subsurface (2-4 weeks). Because the high pH and oxidizing conditions are very localized and temporary, RegenOx will not affect most subsurface structures near the treatment zone. A detailed discussion of materials compatibility follows.

Metals

After RegenOx application, a pH increase is often observed in the treatment area. The actual pH values can range anywhere from 7-12, with pH values of 9-10 most common. Generally, pH values return to neutral or ambient levels within 4 weeks following the injection event. Iron corrosion rates drop at high pH (10-12), so a high pH may actually inhibit iron corrosion. However, as pH increases, corrosion rates increase for aluminum and zinc. If the pH remains high for an extended period of time, this may have implications for buried electrical conduit which are frequently zinc coated iron or aluminum.

In order to summarize all the factors that may lead to metal corrosion, it is customary to use a grading system as an overall guide. In a corrosion index (Table 28-2) in the Chemical Engineer's Handbook (edited by Perry and Green), two categories apply to RegenOx: oxidizing media and alkaline solutions. This index is graded from 0-6 with a rating of 4-6 being good to excellent in terms of compatibility. A summary of the relevant information from this table is shown in Table 1 below. Materials rated a 4 or higher with oxidizing media and alkaline solutions include cast iron, ductile iron, mild steel, stainless steel, Incoloy 825 nickel-iron-chromium alloy, hastelloy alloy C-276 and Inconel 600. Materials receiving low ratings (unsuitable, poor or fair) with oxidizing media include aluminum brass, nickel-aluminum bronze, lead and silver. Caustic conditions may cause problems with silicon iron, aluminum, aluminum brass, nickel-aluminum bronze, lead, titanium and zirconium.

Table 1. General Corrosion Properties of Some Metals and Alloys (from Perry's Chemical Engineers Handbook, Table 28-2)

	Alkaline Solutions	Oxidizing Media
Materials	Caustic and mild alkalies	Neutral or alkaline solutions
Cast iron	4	4
Ductile iron	4	4
Mild Steel	4	4
Ni-Resist corrosion cast iron	5	5
Stainless steel	4-5	6
14% Silicon iron	2	6
Incoloy 825 nickel-iron-chromium alloy	5	6
Hastelloy alloy C-276	5	6
Hastelloy alloy B-2	4	3
Inconel 600	6	6
Copper-nickel alloys up to 30% nickel	5	4
Monel 400 nickel-copper alloy	6	5
Nickel	6	5
Copper and silicon bronze	4	4
Aluminum brass	2	3
Nickel-aluminum bronze	2	3
Bronze	4	4
Aluminum and its alloys	0	0-4
Lead	2	2
Silver	6	2
Titanium	2	6
Zirconium	2	6

Plastics

A wide range of plastics and pipes or Fiberglass Reinforced Plastics (FRPs) may be used in underground service. Each type of plastic will have its own characteristic definition profile. These tanks and pipes are replacing metals due to their greater chemical resistance to corrosion. In many cases plastics can withstand significant concentrations of caustic chemicals. Overall, FRPs withstand a variety of harsh outdoor conditions where they are subjected to high temperatures, ozone and UV over long periods of time.

Reference

Perry's Chemical Engineer's Handbook, Seventh Edition. 1997. Editors: Perry, R. H.; D.W. Green, J.O. Maloney. McGraw-Hill Publishing.

Advanced Chemical Oxidation

Comparison of RegenOxTM to Permanganate

Contaminant Applicability

RegenOxTM rapidly oxidizes a broad range of organic compounds, including petroleum products and chlorinated solvents (both alkanes and alkenes), and is a powerful tool for the remediation of contaminated soil and groundwater. Permanganate-based products, by contrast, have not been successfully used to treat soil and groundwater impacted by petroleum alkanes or chlorinated solvent alkanes such a trichloroethane (TCA).

Relative Oxidizing Capacities

RegenOx is a two-part product composed of an oxidizer/catalyst complex (Part A) and an activator complex (Part B). The RegenOx oxidizer (Part A) contains sodium percarbonate and a surface catalyst as the principal ingredients by mass. Sodium percarbonate has approximately the same oxidizing capacity as potassium permanganate on a per—unit-mass basis. This is based on the formula weights and number of oxidation electrons per formula unit:

Sodium percarbonate (Na₂CO₃)₂(H₂O₂)₃ Potassium permanganate KMnO4

Formula Weight 314 (6-electron oxidant) Formula Weight 158 (3-electron oxidant)

On a per-unit-mass basis:

(3/158)/(6/314) = 99% = (Oxidizing capacity of potassium permanganate)/(Oxidizing capacity of sodium percarbonate)

As shown above, sodium percarbonate and potassium permanganate have almost identical theoretical oxidizing capacity per unit weight. RegenOx is a form of activated percarbonate designed to efficiently degrade a wide variety of contaminants. The added weight of the activator (RegenOx Part B) results in a lower theoretical oxidizing capacity for RegenOx when compared with permanganate on a per-pound basis. However, this is more than compensated by RegenOx' higher selectivity toward contaminant destruction and its ability to treat a much broader spectrum of contaminants.

Cost of Treatment

Table I compares the costs associated with treating a "typical" project site with RegenOx™ to the costs of treating that site with potassium permanganate. The calculations are based on a site that has a soil volume of 16,000 cubic yards with an average perchloroethene (PCE) concentration of 50 ppm and 30 percent porosity. In this scenario, RegenOx™ provides a cost savings of \$39,000 over potassium permanganate, or \$2.43 less per cubic yard treated. Naturally, these cost savings will vary depending on site characteristics; however, this typical example is significant.

Cost		Permanganate*			RegenOx				
Direct Capital Costs	No.	Units	Unit Cost	Cost		No.	Units	Unit Cost	Cost
Direct-Push Mob	1	ea.	\$5,000	\$5,000		1	ea.	\$5,000	\$5,000
Direct-Push Contractor	20	days	\$2,500	\$50,000		20	days	\$2,500	\$50,000
Oxidant Costs	55,689	lbs	\$1.85	\$103,025		16,020	lbs	\$2.00	\$32,040
Activator Costs	0	lbs		\$0		16,020	lbs	\$2.00	\$32,040
	55,689		T	\$158,025		32,040		T	\$119,080

Table 1: Cost Comparison Between RegenOx™ and Permanganate

Most contaminated sites treated by chemical oxidation require retreatment to minimize rebound. Because RegenOx uses a true catalyst (i.e., in both Part A and Part B), which remains active in the subsurface for years, retreatment costs will be significantly lower. For retreatment, the use of RegenOxTM in the scenario described above provides a cost savings of \$55,000 over potassium permanganate, or \$3.44 less per cubic yard (see Table 2). Again, the cost savings achieved by using RegenOx will vary depending on site characteristics.

Cost		Permanganate*			 RegenOx			
Direct Capital Costs	No.	Units	Unit Cost	Cost	No.	Units	Unit Cost	Cost
Direct-Push Mob	1	ea.	\$5,000	\$5,000	1	ea.	\$5,000	\$5,000
Direct-Push Contractor	20	days	\$2,500	\$50,000	 20	days	\$2,500	\$50,00
Oxidant Costs	55,689	lbs	\$1.85	\$103,025	 16,020	lbs	\$2.00	\$32,04
Activator Costs	0	lbs		\$0	8,010	lbs	\$2.00	\$16,02
	55 689	T		\$158 025	 24 030	l''''	T	\$103.06

Table 2: Retreatment Cost Comparison Between RegenOx™ and Permanganate

Safety

RegenOx is engineered for ease of handling in the field and is safely mixed without the risks and potential hazards associated with other chemical oxidants, such as permanganate-type products. Permanganate, especially sodium permanganate, is a highly reactive material that can, if contacted with clothing and or paper products, result in fire. (See an example in Figure 1.)

^{*} P. Block and W. Cutler, "Klozur™ Activated Persulfate for Site Remediation: Comparative Evaluation of Treatment Efficacy and Implementation Costs.", Presented at 4th International Conf. on Oxidation and Reduction technologies for In-Situ Treatment of Soil and Groundwater, October 23-27, 2005.

^{*} P. Block and W. Cutler, "Klozur™ Activated Persulfate for Site Remediation: Comparative Evaluation of Treatment Efficacy and Implementation Costs.", Presented at 4th International Conf. on Oxidation and Reduction technologies for In-Situ Treatment of Soil and Groundwater, October 23-27, 2005.

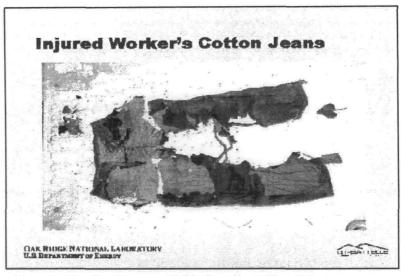


Figure 1: Results of Improper Safety Procedures When Using Permanganate

Longevity

RegenOxTM remains effective in the subsurface for a period lasting approximately 15 days to 1 month. The length of time it will last is adjustable by adding more or less of the Part B activator. However, after the designed period of effectiveness ends, the product is spent. In comparison, permanganate can persist in the subsurface for months, causing an undesired effect as the remaining material may surface in storm drains and surface water.

Formation of MnO₂

The end product of permanganate oxidization is manganese dioxide (MnO₂), which is precipitated in the subsurface. This compound, once formed, interferes with the establishment of conditions suitable for reductive dechlorination, thus working against beneficial bioremediation following chemical oxidation. Additionally, in the presence of dense nonaqueous-phase liquid (DNAPL) contaminants, MnO₂ formation is known to encrust DNAPL ganglia, often retarding the dissolution of the material. This ultimately and negatively affects the remediation process by inhibiting efficient dissolution and treatment of the subsurface contamination. RegenOx, in contrast, does not produce MnO₂ and does not produce any treatment-inhibiting byproducts.

Summary

The information written in this technical bulletin provides compelling evidence that when comparing RegenOx with permanganate, RegenOx is clearly superior in many ways. Relative to material efficiency, cost-effectiveness, safety, ease of use, and post-bioremediation compatibility, RegenOx is clearly the better choice.

For more information on RegenOx or a free application design and cost estimate contact Regenesis at 949-366-8000 or visit www.regenesis.com.

Advanced Chemical Oxidation

Comparison of RegenOxTM to Persulfate

Activation

RegenOxTM is a two part product composed of an oxidizer/catalyst complex (Part A) and an activator complex (Part B). The activation of RegenOx is carried out by simply mixing Part A and Part B together in an on-site tank prior to injection. This is a very safe and easy operation.

Conversely, the activation of persulfate involves complex and often very hazardous operations. Persulfate activation is often accomplished by injecting concentrated hydrogen peroxide or sodium hydroxide solutions under high pressure resulting in a dangerous exothermic reaction. These activities present a significant safety concern for those applying persulfate solutions. Also, the serial application of activator solutions into pre-injected persulfate solutions often can result in displacement of un-activated persulfate away from the treatment area.

Relative Oxidizing Capacities of RegenOxTM and Persulfate

RegenOx oxidizer (Part A) contains sodium percarbonate and a surface catalyst (patent pending), as the principal ingredients by mass. Sodium percarbonate has more than two times the oxidizing capacity of sodium persulfate on a per unit weight basis. The direct comparison is based on the formula weights and number of oxidation-electrons per formula unit:

Sodium percarbonate (Na₂CO₃)₂(H₂O₂)₃ Formula Weight 314, (6-electron oxidant) Sodium persulfate Na₂S₂O₈ Formula Weight 238, (2-electron oxidant)

On a per-unit-mass basis:

(2/238)/(6/314) = 44% = (Oxidizing capacity of sodium persulfate)/(Oxidizing capacity of sodium percarbonate)

When the comparison is done for activated versions of these oxidants, we find that RegenOx is still favored on a per-pound basis. How much depends directly on the amount of activator used for each. Consider a common case where RegenOx is used in a 1:1 ratio of Part A to Part B, and sodium persulfate activator is used in a ratio of 1:0.2 (persulfate to activator). This gives an adjusted ratio of oxidizing capacities on a per-unit-mass basis:

(44%)(2/1.2) = 73% = (oxidizing capacity of activated persulfate)/(oxidizing capacity of RegenOx @1:1).

If this math is confusing, think about dilution: As applied, the total weight of RegenOx is 2x that of just part A. As applied, activated persulfate weight is 1.2x that of just persulfate. Hence the ratio of 2/1.2.

Note that we use a large quantity of RegenOx activator in typical designs, and the oxidizing capacity of RegenOx on a per-pound basis could be increased further by cutting down on the amount of Part B for designs where this makes sense.

In summary, the stoichiometric quantity of activated sodium persulfate required to treat a contaminant mass is about 1/3 more (by weight) than the quantity of RegenOx required to treat that same mass.

RegenOxTM Pricing Relative to Klozur® Sodium Persulfate per Application

A realistic cost comparison can be derived by employing a hypothetical "typical" site with a volume of 16,000 cubic yards with an average perchloroethene contamination (PCE) concentration of 50 ppm and 30% porosity. Under this typical scenario RegenOx offers a cost savings of \$13K over sodium persulfate or \$0.82 less per cubic yard.

Table 1: Cost Comparison Between RegenOx™ Oxidation System and Klozur® Sodium Persulfate

Cost		Sodium Persulfate*			RegenOx™				
Direct Capital Costs	No.	Units	Unit Cost	Cost	No.	Units	Unit Cost	Cost	
Direct-Push Mob	1	ea.	\$5,000	\$5,000	1	ea.	\$5,000	\$5,000	
Direct-Push Contractor	25	days	\$2,500	\$62,500	20	days	\$2,500	\$50,000	
Oxidant Costs	48,137	lbs	\$1.20	\$57,764	16,020	lbs	\$2.00	\$32,040	
Activator Costs	10,697	lbs	\$0.65	\$6,953	16,020	lbs	\$2.00	\$32,040	
	58,834			\$132,217	32,040			\$119,080	

^{*} P. Block and W. Cutler, "Klozur® Activated Persulfate for Site Remediation: Comparative Evaluation of Treatment Efficacy and Implementation Costs.", Presented at 4th International Conf. on Oxidation and Reduction technologies for In-Situ Treatment of Soil and Groundwater, October 23-27, 2005.

Most chemical oxidation sites require product re-application to minimize rebound. Because RegenOxTM uses a true catalyst (i.e in both Part A and Part B) which will remain active in the subsurface for years, re-application costs will be significantly less on subsequent injections. For reapplication, the use of RegenOx in the scenario described above offers a cost savings of \$29K over sodium persulfate or \$1.82 less per cubic yard (Table 2).

Table 2: Re-application Cost Comparison Between RegenOxTM Oxidation System and Klozur® Sodium Persulfate

Cost		Sodium Persulfate			RegenOx™			
Direct Capital Costs	No.	Units	Unit Cost	Cost	No.	Units	Unit Cost	Cost
Direct-Push Mob	1	ea.	\$5,000	\$5,000	1	ea.	\$5,000	\$5,000
Direct-Push Contractor	25	days	\$2,500	\$62,500	20	days	\$2,500	\$50,000
Oxidant Costs	48,137	lbs	\$1.20	\$57,764	16,020	lbs	\$2.00	\$32,040
Activator Costs	10,697	lbs	\$0.65	\$6,953	8,010	lbs	\$2.00	\$16,020
	58,834			\$132,217	24,030		1	\$103,060

^{*} P. Block and W. Cutler, "Klozur® Activated Persulfate for Site Remediation: Comparative Evaluation of Treatment Efficacy and Implementation Costs.", Presented at 4th International Conf. on Oxidation and Reduction technologies for In-Situ Treatment of Soil and Groundwater, October 23-27, 2005.

Safety/ Material Compatibility

RegenOx is engineered for ease of handling in the field and is safely mixed without the safety risks and hazards attendant to other chemical oxidant such as persulfate-type products. The activation of persulfate poses significant safety risks as this process usually entails the use of concentrated hazardous fluids injected under high pressure.

The use of persulfate and the attendant activator solutions also raises significant materials compatibility issues. The use of activated persulfate can lead to corrosion and damage of underground structures as well as the tooling used to apply the material (figure 1).



Figure 1. (Left) a corroded pump fitting that required replacement after one day of operation using sodium persulfate. (Right) a new fitting for sake of comparison.

Longevity

RegenOx remains effective in the subsurface for a period of time lasting from about 15 days to one month. The length of time it lasts is adjustable by adding more or less of the Part B Activator. In comparison, activated persulfate has a longevity range of only several days time.

Klozur(®) is a registered trademark of FMC Corporation

Advanced Chemical Oxidation

Carbonate Scavenging

What is "Carbonate Scavenging?"

In environmental applications of free-radical mediated oxidation chemistry, much ado has been made about the potential for "carbonate scavenging." This term is meant to describe the process by which the carbonate ion loses an electron to become the carbonate radical (CO_3^-) .

Carbonate Radical Adds to Longevity

The carbonate radical is a secondary radical that usually results from the reaction of hydroxyl radical with carbonate/bicarbonate in chemical oxidation processes. As such, carbonate is known as a hydroxyl radical "scavenger" in the advanced oxidation process literature. It should be noted that the resulting carbonate radical is not an end product, but rather a reactive intermediate. Compared to a hydroxyl radical, it reacts with target groundwater contaminants more slowly which, in fact, may be advantageous. In the treatment of groundwater *in-situ*, extremely fast oxidant decomposition is a disadvantage. Time is needed for the chemical oxidant to come in contact with the contaminant because of incomplete mixing and other distribution issues in the subsurface. Therefore, an oxidant with some longevity offers a better chance of being distributed and therefore can be more effective in groundwater remediation. L2

What is the Role of Carbonate in RegenOx? "One man's scavenging is another man's stabilization"

The percarbonate-based RegenOx treatment system offers reasonably fast contaminant reduction rates and sufficient longevity to offer cost-effective distribution. RegenOx is a catalyzed form of the powerful chemical oxidant percarbonate. Percarbonate is often referred to as solid hydrogen peroxide as it is a stabilized form of hydrogen peroxide whereby three molecules of hydrogen peroxide are bound to two carbonate molecules ((Na₂CO₃)₂(H₂O₂)₃). When placed into a contaminated aquifer, the percarbonate is slower to react than hydrogen peroxide alone, but still offers rapid contaminant degradation in the presence of the catalyst system. The presence of carbonate slows the destruction of peroxide, but does not lower the overall capacity of the oxidant. The formation of the carbonate radical ("scavenging") adds to the stability of the peroxide in the percarbonate. In controlled laboratory experiments, researchers found that the net amount of contaminant destruction per hydrogen peroxide consumed did not significantly change in the presence of carbonate. Carbonate only reduced the rate of hydrogen peroxide decomposition.³

Summary

Under the conditions of RegenOx oxidation it is likely that some carbonate radical is formed. However, it is not a terminal end product, but rather an oxidant itself. It is important to note that carbonate radical is a reactive species that can contribute to the overall oxidation of contaminants. It is not a terminal pathway or a "scavenger" as many have described it. Carbonate radical is not the major active species in RegenOx as applied; however, the small quantities that are generated do contribute to the oxidation of contaminants and intermediates.

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- 1. Huang, Jipin and Mabury S., Steady-State Concentrations of Carbonate Radicals in Field Waters. *Environmental Toxicology and Chemistry*. August 2000, 2181-2188.
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- 3. Valentine R. and Wang A., Iron Oxide Surface Catalyzed Oxidation of Quinoline by Hydrogen Peroxide. *Journal of Environmental Engineering*. January 1998.

Advanced Chemical Oxidation

Treatment of Petroleum Hydrocarbons: When to use RegenOxTM vs. ORC Advanced[®]

Introduction

The in-situ treatment of petroleum hydrocarbon contamination in soil and groundwater presents a unique set of conditions. This is due not only to the variability and complexities inherent in the subsurface environment, but also to the variable nature of the contaminants themselves. When one refers to contamination generally as "petroleum hydrocarbons," they are referring to a very broad range of chemicals including very short- to very long-chain alkanes, and single-ring, soluble aromatic structures to multiple-ring, less soluble polyaromatic structures. It is important to understand what specific range of hydrocarbons is to be the target of an in-situ treatment program and to select a remedy that best achieves the overall goal of the remediation.

Total Petroleum Hydrocarbons

The term "total petroleum hydrocarbons" or "TPH" does not describe a compound, but theoretically describes a group of chemicals. TPH is also an acronym used to describe a group of analytical methods used in the environmental industry to measure the entire suite of petroleum-derived compounds potentially available in one sample. Laboratories perform TPH analyses differently depending on their location, applicable regulatory requirements, sample type, and client preferences.

Unfortunately, TPH analyses often measure not only the petroleum-derived compounds present, but also natural background organic matter in the sample (containing organics such as organic acids). Sometimes a "silica gel cleanup" of the sample is performed prior to the analysis to minimize the effects of naturally occurring organic matter. Employing this technique results in a more accurate estimate of the petroleum-derived compounds. (A more detailed description of TPH analysis is presented in the Regenesis Technical Bulletin 10.0 TPH Analysis: Analytical Challenges and Recommendations)

Biodegradation: Use of ORC Advanced®

ORC Advanced® stimulates the in-situ aerobic biodegradation of petroleum hydrocarbons. This approach is a well-documented, robust treatment that efficiently degrades bio-available (soluble) contaminants dissolved in the groundwater and sorbed onto soil in contact with groundwater. The use of ORC Advanced on a complex mixture of hydrocarbons, as measured by TPH analysis, will degrade the more bio-available contaminants in contact with groundwater, leaving the more insoluble fractions behind after the oxygen release is complete. Serial applications of ORC Advanced at a site will continually degrade the more soluble fractions of contaminants, leaving less and less soluble fractions evident by the results of TPH analysis.

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REGENESIS RegenOx Tech Bulletin 8.0

The use of ORC Advanced to stimulate the in-situ biodegradation of short- to moderate-chain alkane-type TPH-range contaminants (gasoline-diesel range) is a very sound approach when low to moderate concentrations of these contaminants are present in the groundwater, and when the sorbed mass of these contaminants (the source of the dissolve contaminants) is thought to be low. Where high concentrations of contaminants are sorbed to the subsurface soil (either because of the adsorptive capacities of the soil matrix or because the TPH contaminants are long-chained, slower-to-desorb compounds), the use of ORC Advanced may require too much time and expense to treat by biodegradation compared to other remedial alternatives.

Chemical Oxidation: Use of RegenOx

Chemical oxidation of gasoline or diesel fuel contamination using any oxidation reagent is a very complex phenomenon, resulting in a myriad of partial oxidation products and contaminant mass equilibrium shifts (from sorbed to dissolved phase). Certain species, such as the aromatic hydrocarbons (e.g., benzene, toluene, ethylbenzene, and xylenes [BTEX], polyaromatic hydrocarbons [PAHs]), are rapidly activated and oxidized partially, if not entirely. Conversely, alkanes are slower to activate and oxidize, leaving a greater proportion of partially oxidized alkanes present. As a result of oxidation and pH shifts, as well as changes in contaminant and soil matrix chemistry, a temporary increase in the soluble fractions may occur post-application.

From an analytical standpoint, if one were simply focusing on the benzene and toluene constituents within a gasoline spill in <u>groundwater</u> subjected to RegenOx treatment, one could expect to see a rapid degradation of the target constituents. RegenOx, in adequate supply, would activate and oxidize the more easily degraded benzene and toluene. A scan of the aromatic fractions by typical volatile organic compound (VOC) methods (e.g., USEPA Method 8260-GC/MS) usually shows a decrease in BTEX compounds.

If, instead, one were to measure the same treatment results using a TPH-type analysis of groundwater, a much different result could be obtained. The TPH-type analysis, instead of showing degradation of the dissolved benzene and toluene, could show an increase in the total dissolved mass of "total petroleum hydrocarbons." The increase in TPH would likely be due to partial oxidation of sorbed contaminants bound to the soil matrix that were transformed via RegenOx (or another chemical oxidant) to more soluble hydrocarbons in groundwater. This results in the increase in soluble compounds measured by the TPH-type analysis.

For project sites where TPH-type analyses are to be used to measure remediation performance, some adjustments to customer expectations should be made. First, the customer should be made aware of the vagaries of typical TPH analyses and how they are impacted by RegenOx chemistry. Second, because RegenOx (or any chemical oxidant) is best used to reduce sorbed or soil-matrix-bound contaminant mass, soil samples should be analyzed as well as groundwater. By employing RegenOx, the sorbed contamination is oxidized (for some constituents more than others) and drawn into the dissolved phase by increasing the solubility. Once in the soluble, more-bio-available state, the partially oxidized contaminants are readily biodegraded given adequate remaining oxygen from the RegenOx application and/or from a subsequent ORC-Advanced application. This will take time, possibly months, depending on site conditions. Therefore, monitoring both soil and groundwater for several months after RegenOx treatment may be required to accurately assess treatment performance.

Product Recommendation

When treating petroleum hydrocarbons in groundwater, each site has specific conditions and project goals. There are no hard-and-fast rules for when to use RegenOxTM and when to use ORC-AdvancedTM for these sites. However, based on sound science and project experience, Regenesis has developed the following recommendations for the use of its products for petroleum hydrocarbon remediation.

Recommended Product Selection
Based on Groundwater Contaminant Concentrations (mg/L)

	ORC Advanced	RegenOx and ORCAdvanced
BTEX (C6-C12)	≤20	>20
TPH-low (<c12)< td=""><td>≤20</td><td>>20</td></c12)<>	≤20	>20
TPH-high (>C20)	≤10	>10
PAH (>C10; e.g., phenanthrene, etc.)	≤1	>1

For more information on RegenOx or a free application design and cost estimate contact Regenesis at 949-366-8000 or visit www.regenesis.com.

RegenOx™

Advanced Chemical Oxidation

Increased Solubility Effects When Treating Total Petroleum Hydrocarbons

Chemical Oxidation Reactions with Petroleum Hydrocarbons

Complete chemical oxidation of petroleum hydrocarbons does not occur within the controlled and extreme environment of the internal combustion engine. So, it is unreasonable to expect that complete oxidation of organic molecules in the subsurface will result from the application of a chemical oxidant. In truth, the application of a chemical oxidant to the subsurface environment results in both complete oxidation and partial oxidation of the contaminants contacted.

When a chemical oxidant is applied to degrade an organic chemical, the initial reaction is "chemical activation," where the long-chain alkanes (CH2-CH2-...CH2) are converted to organic acids (CH2-CH2-CH2-...COOH). These organic acids are much more water soluble due to the polarity induced by the addition of oxygen.

Likewise the treatment of benzene, toluene, ethylbenzene, and xylenes (BTEX) and polyaromatic hydrocarbons (PAHs) by chemical oxidation is a series of reactions first activating the ring structures by the addition of oxygen resulting in greater solubility. The kinetic rate of BTEX and PAH oxidation is considerably faster than that of long-chain alkanes. Therefore, one should expect greater removal of these aromatic compounds when treating a mixed hydrocarbon-contaminated sample. In the case of both alkanes and aromatic hydrocarbons, further chemical oxidation results in stepwise conversions, ultimately resulting in carbon dioxide (complete mineralization).

Note that while reduced petroleum hydrocarbons are rather difficult to biodegrade, once made more soluble by chemical oxidation (activation) they are more easily biodegraded to carbon dioxide and biomass.

Impact of Partial Oxidation on Total Petroleum Hydrocarbon Analyses

In many remediation projects, performance is monitored by groundwater analyses. Often these analyses employ techniques used to measure total petroleum hydrocarbons (TPH), which is a simple measure of general hydrocarbon compounds. (The use of TPH analyses is the subject of RegenOx Technical Bulletin 10.0) Because of the very nature of the chemical oxidation process and its tendency to produce more water-soluble partial oxidation intermediates, one should expect to see an increase in dissolved-phase hydrocarbon species in the early stages of treatment. This is the direct result of a reduced amount of petroleum hydrocarbons bound to subsurface matrix (sorbed) becoming partially oxidized and moving into solution at the site. To distinguish between the dissolved, reduced petroleum hydrocarbon contaminant in the sample and the partially oxidized products, one can apply a silica gel filtration step in the analytical process (as described in RegenOx Technical Bulletin 10.0).

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Before sampling to determine final chemical oxidation performance, it is important to allow for partially oxidized product to further biologically oxidize and to reestablish an equilibrium condition with the subsurface matrix material.

Contaminant Partitioning Challenges

Soil is a very complex mixture of numerous naturally occurring organic and inorganic chemicals. Many physical, chemical, and biological processes are occurring in soil, and all of these processes will be affected by chemical oxidation treatments, including RegenOxTM. Understanding these effects and their interactions is important for predicting the effectiveness of RegenOxTM treatment in various situations, and to avoid unintended consequences.

In the typical model for the partitioning of organic matter to soil, the organic matter in most soil is intimately bound to clay as a clay-organic complex (Dragun, 1998). As a result, two major types of adsorbing surfaces are available to an organic chemical: clay-organic and clay alone. The relative contribution of organic and inorganic surface areas to adsorption depends on the extent to which the clay is coated with organic matter. The influence of clay on organic chemical adsorption can be significant, especially in soil with organic matter content below 1 percent. For example, the adsorption of polychlorinated biphenyls (PCBs) in clayey subsurface soil with an organic carbon content of 0.4 percent is greater than PCB adsorption to topsoil with an organic carbon content of 1.2 percent (Dragun, 1998). Subjecting these adsorptive surfaces to chemical oxidation can greatly effect the partitioning onto the surfaces, thereby shifting the equilibrium concentrations of dissolved versus sorbed contaminant mass.

Adsorption characteristics are specific to the chemical of concern, and are generally influenced by molecular size, hydrophobicity, and molecular charge. These chemical characteristics affect adsorption to soil by influencing adsorption mechanisms generally involving van der Waal's forces, hydrogen chemical bonds, and ionic interactions. Koc is typically used to describe the sorptive characteristics of a chemical. However, using Koc has many caveats (Dragun, 1998), Koc is an experimentally determined value, and the values reported in the literature for a given compound can vary widely. This creates large margins of error when using low groundwater concentrations to calculate the size of a large sorbed-phase contaminant mass. Therefore, real life adsorption systems are not easily modeled, and the effect of chemical oxidation cannot be predicted with any precision.

pH Effects

The addition of basic materials, like RegenOxTM, to soil will have many different effects. Depending on the buffering capacity of the soil, base can dissolve base-soluble minerals, changing the absorptive capacity of the soil for organic materials. Under alkaline conditions, the surfaces of soil particles can acquire negative electrostatic charges giving them a lower affinity for charge-neutral hydrophobic species like petroleum hydrocarbons. In addition, alkaline conditions promote the saponification of fatty acids present from both chemical oxidation and naturally decomposing organic matter. The resulting carboxylates are surfactants that can shift the balance of hydrocarbon contamination from soil into the groundwater. One can consider this a kind of soil washing effect generated by the presence of newly formed surfactants.

Summary

Chemical oxidation (e.g., by RegenOxTM) rapidly oxidizes many organic compounds and is a powerful tool for the remediation of contaminated soil and groundwater. However, it is important for the practitioner to make a realistic assessment of site characteristics and treatment objectives, and judge performance expectations accordingly.

The application of chemical oxidation technology to the subsurface will result in both complete oxidation of the contaminant of concern as well as partial oxidation. Partial oxidation will result in greater solubility of those hydrocarbons bound in the subsurface as sorbed mass. This can result in elevated dissolved-phase hydrocarbon measurements using some analytical methods. Additionally, the oxidation of the subsurface matrix itself, as well as pH effects imparted by the chemical oxidants, can result in elevated hydrocarbon concentrations in the dissolved phase.

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For more information on RegenOx or a free application design and cost estimate contact Regenesis at 949-366-8000 or visit www.regenesis.com.



Chemical Oxidation of VOCs - Ex Situ Soil Treatment

OBJECTIVE

This pilot scale study designed and undertaken by *RemedX* compared chlorinated hydrocarbon (CHC) destruction by three chemical oxidant additions: solid permanganate, permanganate solution and RegenOxTM under identical treatment conditions. Treatment effectiveness of the additions were compared with each other and with an oxidant-free (water only) control to quantify physical losses such as volatilization during soil mixing. The results from this pilot study will be used to evaluate the feasibility of a full scale *ex situ* soil treatment application.

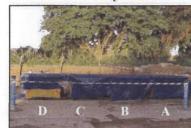
PILOT TEST METHODS

1. SOIL HOMOGENIZATION An excavator mixed the bulk soil.



2. SOIL SPLIT INTO 4 SKIPS

The bulk soil was split and labelled by oxidant treatment.



SKIP A – KMnO₄ Powder SKIP B – KMnO₄ Solution SKIP C – RegenOxTM SKIP D – None/Control

3. BASELINE SAMPLING

Baseline samples were obtained with a hand auger at 0.15 m depth and field PID readings were taken to confirm homogenization. For each skip, 2 composite samples of 5 prior samples were analyzed for Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (sVOCs), Soil Moisture, Total Organic Carbon (TOC) and grain size. The baseline sampling indicated the soil homogenization process had been effective.





4. OXIDANT DELIVERY AND SOIL MIXING

In Skip A, permanganate powder was added and mixed with the excavator. In Skip B, permanganate solution was sprayed and mixed with the excavator. In Skip C, RegenOxTM oxidant powder (Part A) and RegenOxTM activator gel (Part B) were added by hand and then mixed with the excavator. Skip D was the untreated control.



RegenOxTM Part A



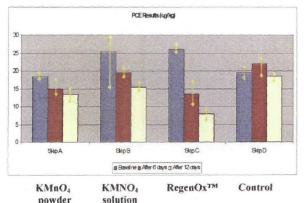
RegenOxTM Part B

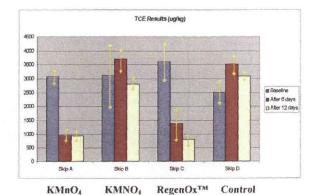


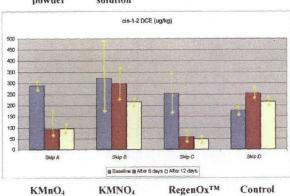
Reaction

RESULTS

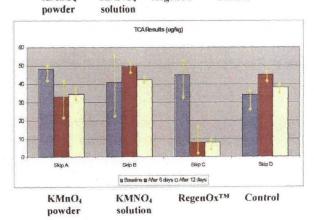
Little or no reduction of any contaminant was observed in either the permanganate solution treatment or the control over the 12 day test period. In contrast, significant reductions in trichloroethene (TCE) and cis-1,2 dichloroethene (DCE) were measured in Skips A (permanganate power) and Skip C (RegenOxTM). Significant reductions of perchloroethene (PCE) and trichloroethane (TCA) were also observed in Skip C (RegenOxTM) as compared with the other treatments. This was most marked for TCA where an 80% reduction was observed in the RegenOxTM treatment whilst other treatments did not differ significantly from the control (no treatment). The likely reason for unsatisfactory results in Skip B (permanganate solution) was the limited amount of oxidant delivered due to the high moisture content of the soil. The results showed no significant changes in total organic carbon (TOC) and moisture in any of the samples, regardless of treatment.







solution



CONCLUSIONS

powder

- RegenOxTM can be effectively used for ex situ soil treatment with less material handling problems than liquid permanganate solution.
- Both Skip A (powdered permanganate) and Skip C (RegenOxTM) showed good reductions of TCE and DCE.
- RegenOxTM treated a wider range of CHCs than permanganate, with statistically better results for DCE, PCE and TCA and evidence of on-going contaminant reduction through the test period.

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RegenOx Treats Mixed Chlorinated Solvent and Hydrocarbon Plume

REGENOXTM CHEMICAL OXIDATION TREATMENT

RegenOx uses a solid alkaline oxidant containing sodium percarbonate complex which is activated using a multi-part catalytic formula to maximize in situ performance. The product is delivered as two parts that are combined and injected into the subsurface using common drilling or direct-push equipment. Once in the subsurface, the combined product produces an effective oxidation reaction comparable to that of Fenton's Reagent yet without a violent exothermic hazard. As a result of this reaction RegenOx safely, effectively and rapidly destroys a wide range of contaminants in both soil and groundwater.

SITE SUMMARY

Groundwater beneath a chemical distribution facility was contaminated with toluene, ethyl benzene, xylenes, vinyl chloride, cis-1,2-dichloroethene, perchloroethene and methyl isobutyl ketone (MIBK). RegenOx was selected to quickly reduce contaminant concentrations in the mixed chlorinated solvent and hydrocarbon plume. Two RegenOx direct-push applications occurred in August and September of 2005.

REMEDIATION APPROACH

Remediation Objective: Reduce concentrations of toluene, ethyl benzene, xylenes, PCE, VC, cis-DCE, toluene and methyl isobutyl ketone (MIBK)

> Application Type: Injection point grid application

> Product: RegenOx

➤ Quantity Applied: 1st application: 1890 lbs. RegenOx

2nd application: 1500 lbs. RegenOx

Application Rate: 20-30 lbs./ft.
 Injection Spacing: 6 ft. on-center

SITE CHARACTERISTICS



General

Name: ConfidentialLocation: Alberta

> Industry: Chemical Distribution Facility

Hydrogeology

> Treatment Area: 2500 ft²

> Soil Type: Clay

➤ Groundwater Velocity: ~ 0 ft./day

> Depth to Groundwater: 5 ft.



Figure 2. Site Layout Photo

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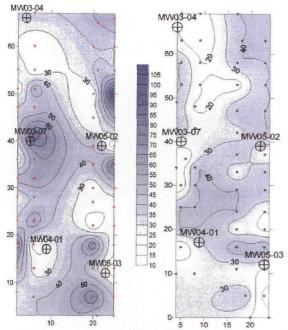


Figure 3. Distribution of RegenOx in heterogeneous subsurface (relative units): 1st injection (left) and 2nd injection (right)

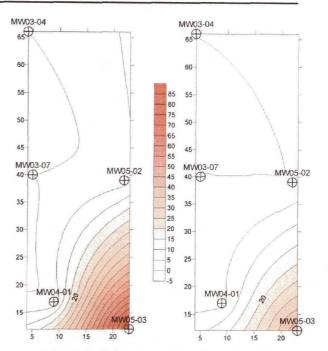


Figure 4. Toluene concentrations (mg/L) pre-injection July 2005 (left) and post-injection Oct 2005 (right)

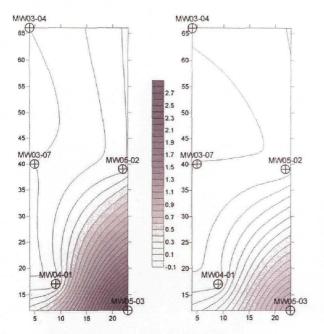


Figure 5. Ethyl benzene concentrations (mg/L) pre-injection July 2005 (left) and post-injection Oct 2005 (right)

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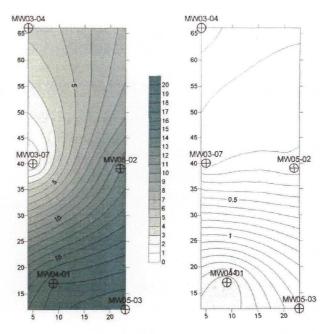


Figure 6. Vinyl chloride concentrations (mg/L) pre-injection July 2005 (left) and post-injection Oct 2005 (right)

Table 2. Contaminant Reduction with RegenOx in MW 05-03

Analyte (mg/L)	Pre-RegenOx	Post-RegenOx	% Reduction
Toluene	87	44	50
Ethyl Benzene	2.7	0.91	66
Xylenes	15	5.8	61
Vinyl Chloride	20	1.2	94
Cis 1,2-dichloroethene	25	9.2	63
Tetrachloroethene	.054	.013	76
Methyl Isobutyl Ketone	240	53	78

CONCLUSION

Since RegenOx was injected into a clay formation, the application rates varied across the site. Figure 3 shows the RegenOx product distribution based on the injection volumes. Some areas of the formation were able to accept more RegenOx (shown in dark blue) than other areas (shown in white).

Significant contaminant reductions were observed across the site, with vinyl chloride (Figure 6) and MIBK showing the largest percent reductions. In the most contaminated well, MW05-03, contaminant reductions ranged from 24-90% after the first application round. RegenOx application to an expanded treatment area is planned January 2006. Over a short period of 3 months, RegenOx effectively degraded a mixed plume containing chlorinated solvents, BTEX contaminants and MIBK.

CONTACTS

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CHEMICAL OXIDATION REDEFINED

RegenOxTM In Situ Chemical Oxidation Application Instructions

Using Direct-Push Injection (Step-by-Step Procedures)

RegenOx[™] is the new generation of chemical oxidation. RegenOx[™] is a proprietary (patent-applied-for) in situ chemical oxidation process using a solid oxidant complex (sodium percarbonate/catalytic formulation) and an activator complex (a composition of ferrous salt embedded in a micro-scale catalyst gel). RegenOx™ with its catalytic system has very high activity, capable of treating a very broad range of soil and groundwater contaminants including both petroleum hydrocarbons and chlorinated solvents.

Instructions

- 1) Prior to the installation of RegenOxTM, any surface or overhead impediments should be identified as well as the location of all underground structures. Underground structures include but are not limited to utility lines; tanks; distribution piping; sewers; drains; and landscape irrigation systems. The planned installation locations should be adjusted to account for all impediments and obstacles. considerations should be part of the SSHP or HASP.
- 2) Pre-mark the installation locations, noting any points that may have different vertical application requirements or total depth.
- 3) Set up the direct push unit over each point and follow the manufacturer standard operating procedures (SOP) for the direct push equipment. Care should be taken to assure that probe holes remain in the vertical.
- 4) For most applications, Regenesis suggests using 1.5-inch O.D./0.625-inch I.D drive rods. However, some applications may require the use of 2.125-inch O.D./1.5-inch I.D. or larger drive rods.
- 5) Advance drive rods through the surface pavement, as necessary, following SOP.
- 6) Push the drive rod assembly with an expendable tip to the desired maximum depth. Regenesis suggests pre-counting the number of drive rods needed to reach depth prior to starting injection activities.
- 7) After the drive rods have been pushed to the desired depth, the rod assembly should be withdrawn three to six inches. Then the expendable tip can be dropped from the drive rods, following SOP. If an injection tool was used instead of an expendable tip, the application of material can take place without any preliminary withdrawal of the rods.



- 8) In some cases, introduction of a large column of air prior to RegenOxTM application may be problematic because the air can block water flow to the treatment area. This is particularly the case in deep injections (>50 ft) with large diameter rods (>1.5-inch O.D.). To prevent the injection of air into the aquifer during RegenOxTM application, as well as to prevent problems associated with heaving sands, fill the drive rods with water, or the RegenOxTM mixture prior dropping the expendable tip or exposing the injection tool.
- 9) The RegenOxTM percent of the oxidizer in solution should range between 3% to 5%. Although solutions up to 8% may be used, this will likely increase the difficulty of injection due to reactivity. Solutions with greater than 8% oxidizer in solution will result in excess reaction and flocculation prior to injection and are not typically recommended

Measure the appropriate quantity of RegenOxTM Oxidizer for one to four vertical foot of injection into a 55 gallon drum or mixing tank. The volume of water per injection location can be calculated from the following formula:

$$\frac{\text{RegenOx Oxidizer lbs/foot}}{(8.34 \text{ lbs/gal water})(\% \text{RegenOx_Oxidizer solids})} \left[1 - (\% \text{RegenOx_Oxidizer solids})\right]$$

Tighter formations (clays and silts), and even some fine sand formations will likely require higher oxidant percentages since less volume can be injected per location. The following are guides to various RegenOx™ mixing ratios based on the above equation.

- to make a roughly 3% oxidant solution for every 10 lbs of oxidant and 10 lbs of activator (20 lbs total RegenOx™), use 38 gallons of water.
- to make a roughly 4% oxidant solution for every 10 lbs of oxidant and 10 lbs of activator (20 lbs total RegenOx™), use 28 gallons of water.
- to make a roughly 5% oxidant solution for every 10 lbs of oxidant and 10 lbs of activator (20 lbs total RegenOx™), use 22 gallons of water.
- 10) Pour the pre-measured quantity of RegenOx[™] Oxidizer into the pre-measured volume of water to make the desired target % oxidant in solution. NOTE: always pour the Oxidizer into water, do not pour water into the Oxidizer. Mix the water and oxidant with a power drill and paint stirrer or other mechanical mixing device to ensure that the Oxidizer has dissolved in the water.



- Pour the applicable quantity of the pre-mixed RegenOxTM Activator into the oxidant:water solution. Mix the Oxidant and Activator using a power drill paint stirrer or other mechanical mixing device for at least 5 minutes until a homogenous mixture is formed. After mixing the RegenOxTM mixture should be injected into the subsurface as soon as possible.
- 12) Do not mix more RegenOx[™] material than will be used over roughly 1 to 4 feet of injection so as to minimize potential above ground reaction/flocculation prior to injection.
 - Transfer the contents of the mixing tank to the pump using gravity feed or appropriate transfer pump. (See Section 9.2: Pump Selection) For some types of pumps, it may be desirable to perform a volume check prior to injecting RegenOx™
- Circulate RegenOx[™] though the hose and the delivery sub-assembly to displace air in the hose. NOTE: an appropriately sized pressure gauge should be placed between the pump outlet and the delivery sub-assembly in order to monitor application pump pressure and detect changes in aquifer backpressures during application.
- 14) Connect the sub-assembly to the drive rod. After confirming that all of the connections are secure, pump the RegenOxTM through the delivery system to displace the water/fluid in the rods.
- 15) Slowly withdraw the drive rods. Commonly RegenOx[™] injection progress at 1-foot intervals. However, continuous injection while slowly withdrawing single lengths of drive rod (3 or 4 feet) is an acceptable option. The pre-determined volume of RegenOx[™] should be pumped into the aquifer across the desired treatment interval.
- 16) Remove one section of the drive rod. The drive rod may contain some residual RegenOxTM. Place the RegenOxTM-filled rod in a clean, empty bucket and allow the RegenOx to drain. Eventually, the RegenOxTM should be returned to the RegenOxTM pump hopper for reuse.
- 17) Monitor for any indications of aquifer refusal. This is typically indicated by a spike in pressure as indicated or (in the case of shallow applications) RegenOx™ "surfacing" around the injection rods or previously installed injection points. At times backpressure caused by reaction off-gassing will impede the pumps delivery volume. This can be corrected by bleeding the pressure off using a pressure relief/bypass valve (placed inline between the pump discharge and the delivery sub-assembly) and then resume pumping. If aquifer acceptance appears to be low, as indicated by high back pressure, allow sufficient time for the aquifer to equilibrate prior to removing the drive rod.



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- 18) Repeat steps 13 through 23 until treatment of the entire contaminated vertical zone has been achieved. It is recommended that the procedure extend to the top of the capillary fringe/smear zone, or to the top of the targeted treatment interval.
- 19) Install an appropriate seal, such as bentonite, above the RegenOx™ material through the entire vadose zone. Prior to emplacing the borehole seal, we recommend placing clean sand in the hole to the top of the RegenOx™ treatment zone (especially important in holes that stay open). Bentonite chips or granular bentonite should be placed immediately above the treatment zone, followed by a cement/bentonite grout to roughly 0.5 feet below ground surface. Quick-set concrete should then be used as a surface seal.
- 20) Remove and clean the drive rods as necessary.
- 21) Finish the borehole at the surface as appropriate (concrete or asphalt cap, as needed). We recommend a quick set concrete to provide a good surface seal with minimal set up time.
- 22) A proper borehole and surface seal assures that the RegenOxTM remains properly placed and prevents contaminant migration from the subsurface. Each borehole should be sealed immediately following RegenOxTM application to minimize RegenOxTM surfacing during the injection process. If RegenOxTM continues to "surface" up the direct push borehole, an appropriately sized (oversized) disposable drive tip or wood plug/stake can be used to plug the hole until the aquifer pressures equilibrates and the RegenOxTM stops surfacing. If wells are used for RegenOxTM injection the RegenOxTM injection wells and all nearby groundwater monitoring wells should be tightly capped to reduce potential for surfacing through nearby wells.
- Periodically compare the pre- and post-injection volumes of RegenOx[™] in the holding tank or pump hopper using the pre-marked volume levels. Volume level may not be present on all tanks or pump hoppers. In this case, volume level markings can be temporarily added using known amounts of water and a carpenter's grease pencil (Kiel crayon).
- 24) Move to the next probe point, repeating steps 8 through 29. We recommend that the next RegenOxTM injection point be as far a distance as possible within the treatment zone from the previous RegenOxTM injection point. This will further minimize RegenOxTM surfacing and short circuiting up an adjacent borehole. When possible, due to the high volumes of liquid being injected, working from the outside of the injection area towards the center will limit expansion of the plume.



Pump Selection

Regenesis has evaluated a number of pumps and many are capable of delivering RegenOxTM to the subsurface at a sufficient pressure and volumetric rate. However, even though a number of the evaluated pumps may be capable of delivering the RegenOxTM to the subsurface based on adequate pressures and delivery rates, each pump has its own set of practical issues that may make it more or less difficult to manage in a field setting.

In general, Regenesis strongly recommends using a pump with a pressure rating of 200 pounds per square inch (psi) in sandy soil settings, and 800 psi in silt, clay or weathered bedrock settings. Any pump under consideration should have a minimum delivery rate of 5 gallons per minute (gpm). A lower gpm rated pump may be used; however, they are not recommended due to the amount of time required to inject the volume of liquids typically associated with a RegenOxTM injection (i.e. 1,000 lbs of RegenOxTM [500 lbs Oxidant/500 lbs Activator] require roughly 1,100 gallons of water to make a 5% Oxidant solution).

Quite often diaphragm pumps are used for the delivery of chemical oxidants. Generally, these pumps operate pressures from 50-150 psi. Some of these pumps do not have the pressure head necessary to overcome the back pressure encountered in silt and clay lenses. In these cases the chemical oxidant thus ends up being delivered to the surrounding sands (the path of least resistance) and is not delivered to soil with residual adsorbed contamination. The use of a positive displacement pump such as a piston pump or a progressing cavity pump is may be superior because these pumps have the pressure necessary to overcome the resistance of low permeability soils. NOTE: be aware that application at pressures that are too high may over-consolidate the soil and minimize the direct contact of the oxidant. The key is to inject at a rate and pressure that maximizes the radius of influence without causing preferential flow. This can be achieved by injecting at the minimum pressure necessary to overcome the particular pressures associated with your site soil conditions.

Whether direct injection or wells are used, it is best to start by injecting RegenOxTM outside the contaminated area and spiral laterally inwards toward the source. Similarly, RegenOxTM should be applied starting vertically at the bottom elevation of contamination, through the layer of contamination, and a couple of feet above the layer of contamination. The reagents can be pushed out from the well bore with some water.

Pump Cleaning

For best results, flush all moving parts and hoses with clean water at the end of the day; flush the injection system with a mixture of water and biodegradable cleaner such as Simple Green.

For more information or technical assistance please call Regenesis at 949-366-8000

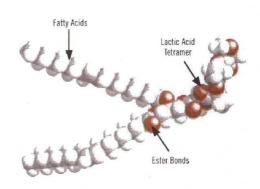
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APPENDIX B

Anaerobic Injection Materials (HRC®/3DMe®)

- Provides free lactic acid, controlled-release lactic acid and long release fatty acids for effective hydrogen production for periods of up to 3 to 5 years.
- - 3-D Microemulsion is 25¢ to 42¢ per pound as applied
- Maximum and Continuous Distribution via Micellar Transport
 - Unlike oil products, 3DMe forms micelles which are mobile in groundwater and significantly enhance electron donor distribution after injection.
- Wide-Area/High Volume Microemulsion Application
 - High volume application increases contact with contaminants and reduces number of injection points required for treatment minimizes overall project cost.

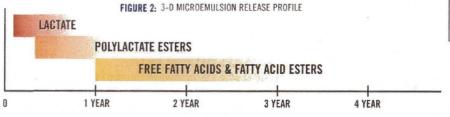
FIGURE 1: THE 3-D MICROEMULSION MOLECULAR STRUCTURE



3-D Microemulsion (3DMe)™ is a form of HRC Advanced® and has a molecular structure specifically designed to maximize the costeffective anaerobic treatment of contaminants in subsurface soils and groundwater. This structure (patent pending) is composed of free lactic acid, controlled-release lactic acid (polylactate) and certain fatty acid components which are esterified to a carbon backbone molecule of glycerin (Figure 1).

3DMe produces a sequential, staged release of its electron donor components. The immediately available free lactic acid is fermented rapidly while the controlled-release lactic acid is metabolized at a more controlled rate. The fatty acids are converted to hydrogen over a mid to long-range timeline giving 3DMe an exceptionally long electron donor release profile (Figure 2). This staged fermentation provides an immediate, mid-range and very long-term, controlled-release supply of hydrogen (electron donor) to fuel the reductive dechlorination process.

Typical 3DMe single application longevity is rated at periods of up to 3 to 5 years. With 5 years occurring under optimal conditions, e.g. low permeability, low consumption environments.



DISTRIBUTION APPLICATION AND

3DMe applications can be configured in several different ways including: grids, barriers and excavations. The material itself can be applied to the subsurface through the use of direct-push injection, hollow-stem auger. existing wells or re-injection wells.

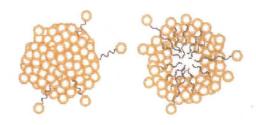
3DMe is typically applied in high-volumes as an emulsified, micellar suspension (microemulsion). The microemulsion is easily pumped into the subsurface and is produced on-site by mixing specified volumes of water and delivered 3DMe concentrate. Detailed preparation and installation instructions are available at www.regenesis.com.

3DMe is usually applied throughout the entire vertical thickness of the determined treatment area. Once injected, the emulsified material moves out into the subsurface pore spaces via micellar transport, eventually coating most all available surfaces. Over time the released soluble components of 3-D Microemulsion are distributed within the aquifer via the physical process of advection and the concentration driven forces of diffusion.

MORE ON MICELLES

Micelles (Figure 3) are groups (spheres) of molecules with the hydrophilic group facing out to the water and the "tails" or lipophilic moiety facing in. They are formed during the 3-D Microemulsion emulsification process and provide the added benefit of increased distribution via migration to areas of lower concentration

FIGURE 3: MICELLE REPRESENTATION



PRODUCT COMPOSITION

MORE ON APPLICATIONS



1-0 M normalsion is delivered in 55 gallon drums, 300 gallon totes, tankers or buckets.



The microemulsion is easily prepared on-site and applied in high-volumes for maximum subsurface distribution.



3-D Microemulsion is typically applied through permanent wells or by using direct-push injection.

PERFORMANCE

Case Study #1

A site in Massachusetts showed high levels of PCE and its daughter products TCE and cis-DCE which had been consistently present for more than two years. 3DMe was applied in a grid configuration around monitoring well #16. In Figure 4, the contaminant concentration results indicate a rapid decrease in the parent product PCE and evidence of reductive dechlorination as demonstrated by the relative increases in daughter products TCE and cis-DCE.

Case Study #2

A site in Florida was characterized with PCE contamination approaching 225 ug/L A total of 1,080 pounds of 3DMe was applied via 16 direct-push injection points to reduce PCE concentrations. Monitoring results in well MW-103 indicated a PCE reduction of approximately 67% within 75 days of the 3DMe application. PCE concentrations continued to decline by 96% one year after application and daughter products remained at low levels. Total Organic Carbon (TOC) levels remained elevated at 17-19 mg/L after 275 days demonstrating the longevity of 3DMe (Figure 5).

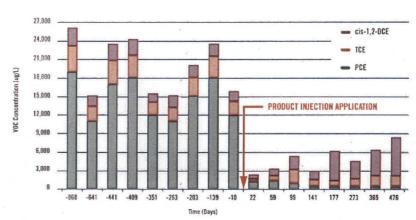


FIGURE 4: MW-16 CONTAMINANT CONCENTRATION DATA

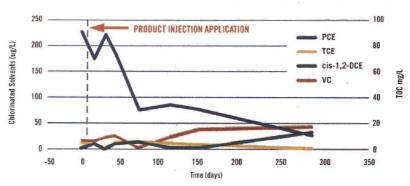


FIGURE 5: MW-103 CONTAMINANT CONCENTRATION DATA

3-D Microemulsion (3DMe)TM

TECHNICAL BULLETIN 1.0

Introduction

3-D Microemulsion (3DMe)TM, a form of HRC Advanced[®], is the new paradigm in time-release electron donors for groundwater and soil remediation. 3DMe is based upon a new molecular structure (patent applied for) designed specifically to optimize anaerobic degradation of contaminants in subsurface environments. This structure incorporates esterified lactic acid (technology used in HRC) and esterified long chain fatty acids. The advantage of this structure is that it allows for the controlled-release of lactic acid (which is among the most efficient electron donors) and the controlled-release of fatty acids (a very cost effective source of slow release hydrogen). Upon injection, the controlled-release of lactic acid dominates serving to initiate and stimulate anaerobic dechlorination. Over time the controlled-release of fatty acids will dominate, acting to continue microbial stimulation. The expected single-injection longevity of this product is 1-2 years and in excess of 4 years under optimal conditions, e.g. concentrated application in low permeability, low consumptive environments.

3DMe is a slightly viscous liquid that incorporates a molecular structure composed of tetramers of lactic acid (polylactate) and fatty acids esterified to a carbon backbone molecule of glycerin.



The image to the left illustrates a ball-and-stick version of the glycerol ester in 3DMe. Oxygen atoms are shown in red, carbon atoms in grey, and hydrogen atoms in white. The long chains represent the fatty acid components of the molecule.



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When 3DMe is placed in water, free lactic acid immediately begins to ferment which initiates reductive dechlorination and subsequent contaminant treatment. Over time the ester bonds begin to cleave, producing dissolved-phase lactic acid and fatty acids. 3DMe also contains free fatty acids for additional electron donating capacity. Thus, 3DMe provides the benefits of lactic acid, a rapidly fermented substrate and excellent hydrogen source, as well as fatty acids, which are slower to ferment and provide hydrogen to a contaminated site over extended time periods. This combination of lactic acid and fatty acids provides a functional longevity of 1-2 years for most sites (>4 years under optimal conditions). 3DMe creates an anaerobic system in a redox range where bacteria known to be responsible for reductive dechlorination flourish. Maintaining these conditions provides maximum utilization of the electron donor for reductive dechlorination, rather than simply providing excess carbon per unit time which can result in excess methane production, as simple soluble substrates often do.

3DMe Attributes:

- o Incorporates proven Hydrogen Release Compound (HRC*) base materials
- Provides a persistent and significant source of hydrogen
- Typical single-injection longevity of 1-2 years and over 4 years under optimal conditions
- o Achieve wide subsurface distribution when applied as microemulsion
- o Easily applied with readily available direct injection equipment

Molecular Diagram

The following chemical structure shows the glycerol ester (patent applied for). The top "prong" is the tetramer of polylactate (look for 4 double bonded O atoms). The middle and bottom "prongs" are fatty acids.



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3-D Microemulsion (3DMe)TM

TECHNICAL BULLETIN 2.0

Subsurface Transport Mechanisms

As described in 3-D Microemulsion Technical Bulletin 1.0 (Introduction), 3-D Microemulsion (3DMe)TM, a form of HRC Advanced[®], is a unique compound (patent applied for) which incorporates esterified lactic acid (the technology used in HRC), with esterified fatty acids. The unmatched advantage of this product is that it allows for the immediate and controlled-release of lactic acid which is among the most efficient electron donors. The controlled-release of proprietary fatty acids provides a cost-effective source of controlled-release hydrogen. This combination of organic acids, in turn, rapidly stimulates reductive dechlorination for extended periods of time up to 4+ years under optimum conditions (e.g. concentrated application in low permeability, low consumptive environments.).

3DMe is NOT Simple Emulsified Vegetable Oil

Vegetable oil is basically insoluble. Thus, to make it amenable to injection into the subsurface, some vendors have added commercial emulsifying agents to simple vegetable oils and produced emulsions claiming that the "stable" emulsion will transport the oil significant distances down-gradient from the injection point. Unfortunately, this is not the case.

When so-called "stabilized" oil-in-water emulsions are forced out of the injection point into subsurface aquifer materials the emulsifying agents are rapidly stripped from the oil droplet due to the zeta potential of subsurface materials (charges on the surfaces of soil particles) adhering to the hydrophilic "heads" of the emulsifying agents, and to organic matter within the aquifer matrix sorbing to the vegetable oil itself. Upon the stripping of the emulsifying agents the oil droplets rapidly coalesce in soil pores creating a separate phase (this is the basis for many de-emulsification filters used in the petroleum production industry). When this coalescence occurs in the aquifer, it retards further migration of any oil emulsion and, in fact, often blocks groundwater flow. Use of emulsified oil products can result in significant lowering of the aquifer hydraulic conductivity within aquifer settings (Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater, Environmental Security Technology Certification Program, US Department of Defense, November 2005.)

3DMe has a balanced HLB

3DMe is composed of molecules that are surface active. That is to say the molecules behave as surfactants, with a hydrophilic or "water loving end", and a lipophilic or "oil loving end". As a result, the molecules tend to align themselves with the hydrophilic ends in the water matrix, while the lipophilic ends bind to organic compounds (such as the contaminant).

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dvanced Technologies for Groundwater Resources

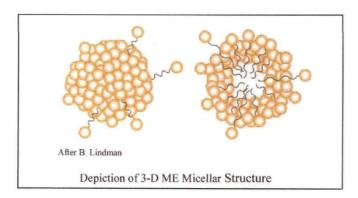
As a measure of the tendency for a molecule to move into water, chemists refer to the Hydrophile/Lipophile Balance index (HLB). The greater the HLB, the higher the tendency for dissolution in water, thus, low HLB molecules are generally pushed out of the water matrix and sorb onto surfaces and to organic compounds within the aquifer material.

3DMe was designed to have a low, yet positive HLB. This gives 3DMe the advantage of being able to sorb organic contaminants (partition), yet have a significant solubility in water allowing for aqueous transport (unlike emulsified oils). A comparison of estimated HLBs for substrates is listed below.

Substance	HLB
Sugars	30
Lecithin	20
3DMe	6
Vegetable Oil	-6

3DMe Forms Micelles

When 3DMe is in water in concentrations in excess of about 300ppm, dissolved molecules of 3DMe begin to spontaneously group themselves into forms called "micelles". In colloidal chemistry this concentration is referred to as the "critical micelle concentration" or CMC. The grouping of the micellar structure is very orderly, with the charged or hydrophilic ends (heads) of the fatty acids facing out to the water matrix and the hydrophobic ends (tails) facing in together. The micellar structures formed from 3DMe are generally spherical, but under certain circumstances can become lamellar. A depiction of a 3DMe micellar structure is shown below:



The size of the 3DMe micelles formed is very small, on the order of .02 to .05 microns in diameter. These will spontaneously form in aquifer waters when the CMC is exceeded. Thus,



by loading the aquifer with volumes of injection water containing 3DMe in excess of approximately 300 ppm, micelles will spontaneously form carrying the 3DMe product further down-gradient.

Mixing and Application

Concentrated Delivery

When applied to the subsurface in concentrated form, 3DMe will behave much like HRC. Once installed the material remains stationary and slowly releases soluble lactic acid and fatty acids which diffuse and advect away from the point of application. In this fashion the engineer is assured of a long-term, constant supply of electron donor emanating from the point of application for a period of up to 4+ years (under optimal conditions). This is particularly attractive when used to treat a flux of contamination from an up-gradient source or when a very long term supply of electron donor is required.

High Volume Delivery

3DMe can also be used to treat large areas in a short period of time by using a high-shear pump to mix the 3DMe with water prior to injection. This mixing generates a large volume of a 3DMe colloidal suspension. The actual suspension of 3DMe generated by this mixing ranges in size from micelles on the order of .02 microns to .05 microns in diameter to "swollen" micelles, also termed "microemulsions", which are on the order of .05 to 5 microns in diameter.

Once injected into the subsurface in high volumes followed by water the colloidal suspension mixes and dilutes in existing pore waters. The micelles/microemulsions on the injection front will then begin to sorb onto the surfaces of soils as a result of zeta potential attraction and organic matter within the soils themselves. As the sorption continues, the 3DMe will "coat" pore surfaces developing a layer of molecules (and in some cases a bilayer). This sorption continues as the micelles/microemulsion moves outward.

Unlike emulsified oil, however, the sorbed 3DMe has a significant capacity to move beyond the point of initial sorption. As the high concentration of 3DMe present in the initial injection volume decreases, bound material desorbs. As long as this concentration exceeds the CMC, micelles will spontaneously form, carrying 3DMe further out in to the contaminated aquifer through advection and diffusion.

Additional Research Underway

Regenesis is currently undertaking a series of laboratory studies and in-field research efforts to further define the extent to which 3DMe suspensions transport under various aquifer conditions. These studies will generate information which will aid in understanding the limitations to the transport of colloidal suspensions under realistic injection/aquifer dispersion conditions.



3-D Microemulsion (3DMe)TM

TECHNICAL BULLETIN 3.0

Micelle Distribution Column Experiment

Background

3-D Microemulsion (3DMe)TM, a form of HRC Advanced[®], is a state-of-the-art specialty chemical substrate developed to provide a low-cost, slow-release electron donor to stimulate the in-situ anaerobic degradation of contaminants in soil and groundwater. Unlike emulsified-oil-type substrates, 3DMe was designed to provide superior distribution in the subsurface, thereby reducing the cost of product application. 3DMe was also designed to avoid the significant reduction in subsurface hydraulic conductivity often associated with emulsified-oil-type substrates. 3DMe is a slightly viscous liquid that incorporates a molecular structure composed of tetramers of lactic acid (polylactate) and fatty acids esterified to a carbon backbone molecule of glycerin.

Subsurface Transport

3DMe achieves superior subsurface distribution through surface-active properties that promote the spontaneous formation of micellar structures (Shah, et al., 1972; Lindman, et al., 1982). This unique characteristic allows for moderate aqueous transport of the substrate prior to its adsorption onto the aquifer matrix where it both partitions organic contaminants from solution and promotes rapid biodegradation through efficient hydrogen generation. (The surface-active properties of 3DMe, formation of micelles, and recommended 3DMe application details are described in Regenesis 3-D Microemulsion Technical Bulletin 2.0.)

Demonstration of 3DMe Movement

It is well known that slow-release electron donors, such as emulsified-oil-type substrates, do not distribute well in soil and groundwater. In fact, extensive experiments using emulsified-oil-type substrates in sand test cells demonstrated that the emulsified-oil substrate moved less than 2 meters, even after 10 days of continuous emulsion feed. Furthermore, no emulsified-oil substrate moved more than 8 meters, regardless of injection volumes, and no additional water volume moving through the sorbed emulsion could facilitate further distribution (Borden, et al., 2005).

Experimental Design

In an effort to analyze the subsurface transport properties of 3DMe relative to the known shortcomings of emulsified-oil-type products, a controlled laboratory experiment was conducted using a dedicated aquifer simulation column (column) that was packed with



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sand. The 6-inch-diameter, 20-foot-long column was constructed of transparent polycarbonate. The column was filled with fine-grained sand and packed to prevent channeling. The pore space was determined to be 30.5 percent (approximately 9 gallons). The column was filled with water by peristaltic pumps at a rate of 2.5 gallons per hour (see Figure 1).

A microemulsion of 3DMe was created by preparing a 1:3 3DMe-to-water mixture using a common high-shear pump, and was further diluted with water to generate a final 1:50 microemulsion. To visually track movement of the microemulsion in the sand column, it was dyed with methylene blue, which is absorbed by the hydrophobic portions of the 3DMe microemulsion. The dye does not partition into water.

After the column was first saturated with water, the 3DMe microemulsion was fed into the column at a rate of 2.5 gallons per hour. After 20 hours, the microemulsion feed was stopped and water was injected into the column at the same rate (2.5 gallons/hour). This water feed continued for 12 hours (about 3.3 pore volumes).

Movement of the dyed microemulsion and resulting dyed micelle suspension were observed visually throughout the study. In addition, water effluent from the column was analyzed for the methylene blue by UV-Visible Spectroscopy. Components of 3DMe in the effluent were also confirmed by direct measurement with both liquid chromatography and infrared analysis.

Results and Discussion

After 13 hours, an estimated 3.6 pore volumes of the 3DMe microemulsion (1:50 product-to-water mixture) had been fed into the column. As expected, due to the unique hydrophile/lipophile balance of the 3DMe material, the bulk of the microemulsion appeared to adhere to the sand surfaces within the first 1 meter of the column, as evidenced by the dark blue color (see Figure 2). However, it was at this time that the first "break through" (material exiting the column) was detected by spectroscopy. Further analysis clearly indicated that the material in the effluent was, in fact, colloidal 3DMe (Micellar suspension), as evidenced by the presence of the intact esters, carboxyl, and carbonyl peaks apparent under infrared spectrum analysis (see Figure 3). While the bulk of the injected 3DMe remained stationary, micelles were forming and carrying the material more than 20 feet, with only 3.6 pore volumes, in less than 13 hours.

Approximately 20 hours after 3DMe injection, the bulk of the microemulsion continued to sorb onto soil near to the injection point (within the first 2 meters of the column), as evidenced by a dark blue color. At that time, the column was switched to a water feed, without any 3DMe, to emulate continued groundwater flow following 3DMe application. A striking pattern began to emerge as a light-blue-colored "front" began to move down the column.



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It is apparent that water continuing to flow past the 3DMe was redistributing the product through the column as suspended micelles, which, in turn, were resorbing onto the column in a forward-moving "front." As more water was fed through the column, the 3DMe continued to redistribute, forming a light-blue-colored pattern (see Figure 4). Throughout the 12-hour period of the water feed, a 3DMe micelle suspension of low concentration was documented exiting the 20-foot-long column, as evidenced by microscopy and validated by liquid chromatography as well as infrared analysis.

Summary

3DMe was designed to achieve superior distribution in the subsurface and the advanced performance capability of the material was clearly demonstrated in a controlled laboratory column study. During the study, it was shown that 3DMe, when injected into the subsurface, initially sorbed onto the sand matrix. However, once in place, the material redistributed gradually through micelle formation and sorption in a distribution "front." 3DMe micelles were documented to move 20 feet through the sand column in 13 hours (3.6 pore volumes). The ability of 3DMe to remain relatively stationary, yet form micelles that continually redistribute, clearly demonstrates the product's superior subsurface distribution capability. This is significant when compared to other electrondonor substrates. Highly soluble substrates such as lactate and sugar solutions rapidly ferment and "wash out," requiring the expense of multiple injections. Emulsified-oiltype products have been clearly documented to sorb within the first 2 meters of the injection and then remain immobile, significantly limiting the effective radius of any injection point. In addition, emulsified oils often coalesce in the subsurface, reducing hydraulic conductivity.

The scientific evidence clearly demonstrates that the unique transport properties of 3DMe make this product an advantageous choice for stimulating effective in-situ anaerobic biodegradation.



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Figure 1
Experimental Packed Column (20-foot-long, 6-inch diameter)

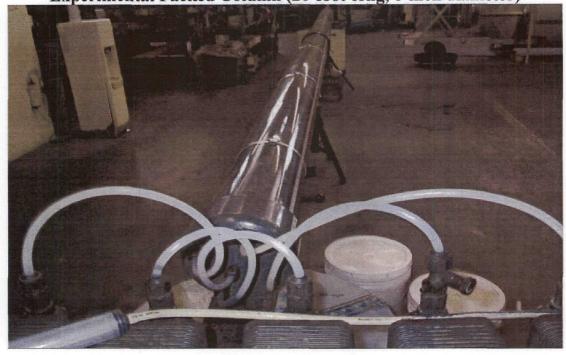


Figure 2
3DMe Movement at 13 hours (3.5 pore volumes)





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Figure 3
Infrared Spectrum of Organic Material Exiting ASV at 13 Hours

13 Hour Sample - Organic Esters and Acids

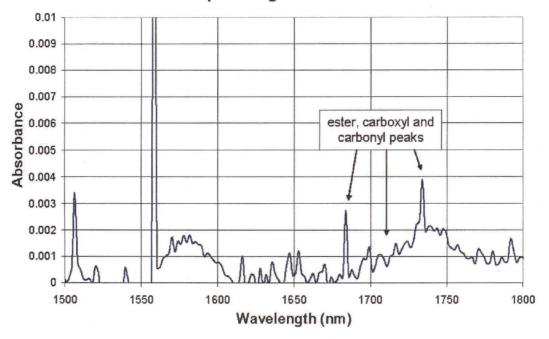
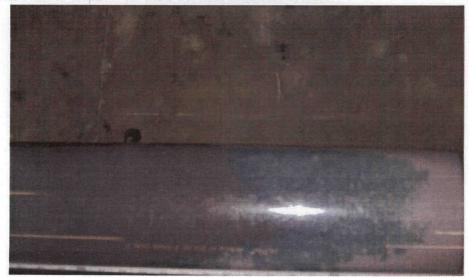


Figure 4
Micelle Formation and 3DMe Redistribution with Water Feed





Advanced Technologies for Groundwater Resource

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3-D Microemulsion[®] Enhances Reductive Dechlorination and Reduces PCE and TCE Concentrations to Non-Detect

CASE SUMMARY

Dry Cleaning Operations, Belleville, IL

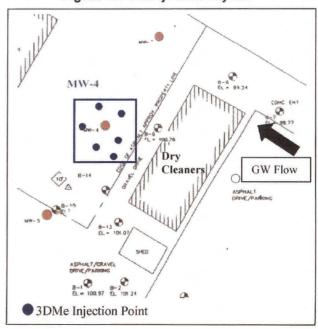
Operations at a dry cleaning facility in Illinois resulted in elevated levels of chlorinated ethenes in the subsurface. Downgradient of the contaminant source (in Well MW-4), the total chlorinated compound concentration was greater than 6,400 parts per billion (ppb), the main contaminant being tetrachloroethene (PCE). A pilot test using Hydrogen Release Compound (HRC®) was initially designed and deployed to produce conditions favorable for the reduction of contaminants. Well MW-4 was the designated sampling point to observe the contaminant reduction. The HRC pilot application was mis-applied over a 20 foot vertical interval instead of the recommended and planned 10 foot interval, resulting in under-dosing of HRC and only moderate treatment performance. A second application was performed 18 months later using the correct dosing and a form of HRC Advanced® known as 3-D Microemulsion (3DMe)TM.

REMEDIATION APPROACH

3DMe is a completely new molecule with staged hydrogen release capabilities and is applied as a microemulsion for enhanced distribution. The 3DMe microemulsion was directly injected at 6 locations surrounding the targeted monitoring well MW-4 (Figure 1). It was injected at a rate of 120 pounds per injection point and at 10 to 20 feet below ground surface (at the correct 10 foot interval). The injection points were spaced approximately 7 feet from one another.

3DMe Injection (ppb)		
Contaminant Concentration		
PCE	5,680	
TCE	301	
cis-DCE	474	
VC	ND	

Figure 1. Pilot Injection Layout



Application Type: Pilot Test

Quantity Applied: 720 lbs

Application Rate: 15 gal/ft

Injection Spacing: 7 feet

Soil Type: Clay

Groundwater Velocity: <0.1 ft/day</p>

Treatment Thickness: 10 feet

Depth to Groundwater: 10 feet

RESULTS

Although HRC was applied and under-dosed in September 2004, moderate increases in the reductive dechlorination process were observed near Well MW-4. The moderate effect resulted in a 50 percent decrease in PCE concentrations. As expected some daughter products were also produced.

Within 30 days of the 3DMe application, PCE was reduced from 5,680 ppb to non-detect followed by a similar reduction in TCE. A reduction of 77 percent was observed in cis-DCE between August 2006 and April 2007. Slight increases in vinyl chloride (VC) and ethene indicated that complete dechlorination was occurring with no stalling effect (Table 2).

Concentrations vs. Time

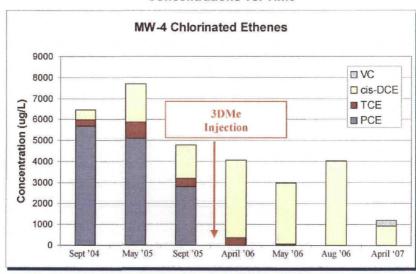


Table 2. Vinyl Chloride and Ethene detection in Well MW-4 (ppb)				
	April 2006	May 2006	August 2006	April 2007
VC	ND	17	25	270
Ethene	3	3	NA	13

CONCLUSION

Biostimulation using 3DMe was successful in treating the target contaminants as a result of the proper dosing/emplacement of the material and overall product performance. In MW-4, PCE and TCE were reduced to non-detect while total chlorinated compounds were reduced by more than 70 percent.

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REGENESIS
Advanced Technologies for Groundwater Resources

3-D MicroemulsionTM Treats PCE, TCE and cis-DCE

SITE SUMMARY

A limited subsurface investigation revealed elevated concentrations of chlorinated compounds in groundwater at a manufacturing facility in Massachusetts. Further assessment indicated past releases of tetrachloroethene (PCE) had occurred relating to a former above ground storage tank housed on-site. PCE levels of approximately 12,000 micrograms per liter (ug/L) and daughter products trichloroethene (TCE) and cis-1,2-dichloroethene (cis-DCE) were measured in the subsurface. Enhanced anaerobic bioremediation using 3-D Microemulsion (3DMe)TM, a form of HRC Advanced[®], was implemented via direct-push application to accelerate reductive dechlorination.

TECHNOLOGY SUMMARY

3DMe is composed of free lactic acid, controlled-release lactic acid (polylactate) and certain fatty acid components which are esterified to a carbon backbone molecule of glycerin. When injected into contaminated soil and groundwater, 3DMe produces a sequential, staged release of its electron donor components. The immediately available free lactic acid is fermented rapidly while the controlled-release lactic acid is metabolized at a more controlled, gradual rate. The fatty acids are converted to hydrogen over a mid-to long-range timeline giving 3DMe an exceptionally long electron donor release profile. This staged fermentation provides an immediate, mid-range and very long-term, controlled-release supply of hydrogen (electron donor) to fuel the reductive dechlorination process.

REMEDIATION APPROACH

> Remediation Objective: Degrade PCE, TCE and cis-DCE

Application Type: Barrier
 Product: 3-D Microemulsion
 Quantity Applied: 960 lbs
 Application Rate: 6 lbs/ft
 Injection Spacing: 5-7.5 ft

SITE CHARACTERISTICS

General

Name: Confidential
 Location: Massachusetts
 Industry: Manufacturing
 Contaminants of Concern:

Table 1. MW-16 Concentrations

Contaminant	Concentration
PCE	12,000 ug/L
TCE	2,300 ug/L
Cis-DCE	1,300 ug/L

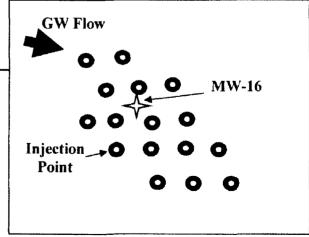


Figure 1. 3DMe Injection Design

Hydrogeology

- > Treatment Area: MW-16 Downgradient of incoming source of contaminants
- > Soil Type: Fine to Coarse Sand with Interbedded Layers of Silt and Clay
- > Groundwater Velocity: unknown
- > Groundwater Flow Direction: Southeast
- > Depth to Groundwater: 4-10 ft

RESULTS

Figure 2: Chlorinated ethene concentrations in MW-16

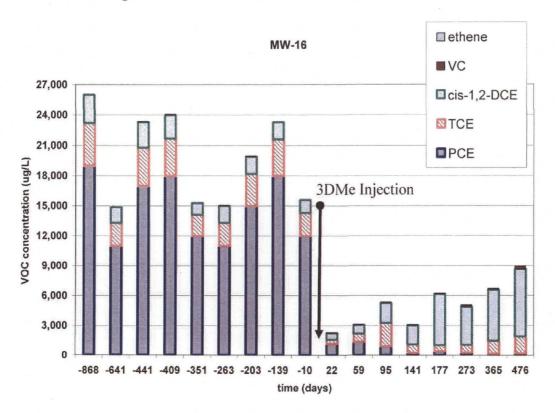


Table 2: Metabolic acid data from MW-16

Table 2. Wetabolic acid data from WW-10					
Day	Lactic acid	Pyruvic acid	Propionic acid	Butyric acid	Acetic acid
-10	0	0	0	0	0
22	1410	3.5	3.5	3.5	35
59	576	0.35	105	0.3	83
95	130	1.7	370	13	130
141	372	3.5	354	116	129
176	222	3.5	357	210	135

Table 3: MW-16 Contaminant and Breakdown Product Table

Note: all units a	re ug/L						
Date	Day	PCE	TCE	cis-1,2-DCE	VC	ethene	
11/25/2002	-868	19000	4200	2800	0		
7/10/2003	-641	11000	2300	1600	0		
1/26/2004	-441	17000	3800	2500	0	26.7	
2/27/2004	-409	18000	3700	2300	0	27.4	
4/25/2004	-351	12000	2100	1200	0		
7/22/2004	-263	11000	2300	1700	0	21.7	
9/20/2004	-203	15000	3200	1700	0	30.9	
11/23/2004	-139	18000	3600	1700	0		
4/1/2005	-10	12000	2300	1300	0		
	3 D M e IN JECTION						
5/3/2005	22	1200	390	650	37	6.8	
6/9/2005	59	1400	800	860	17	6.2	
7/15/2005	95	950	2300	2000	48	9.3	
8/30/2006	141	250	850	1900	52	8.4	
10/04/2006	176	430	600	5100	70	9.8	
1/9/2006	273	300	760	3800	170	11	
4/11/2006	365	180	1300	5100	96	9	
7/31/2006	476	210	1700	6700	290	16	

CONCLUSION

Immediately following the 3DMe application, a rapid and simultaneous decrease in all chlorinated ethenes (both parent and daughter products) was observed. This can be attributed to the partitioning of contaminants into the 3DMe material. Over time, both the 3DMe and the contaminants will be biodegraded resulting in metabolic acid production (from 3DMe) and reductive dechlorination of the contaminants. Three months following the 3DMe application a 98% reduction in PCE (from 12,000 ug/L to 250 ug/L) was observed. This positive trend was sustained over a 14 month period even with a continuing influx of contamination. As a result of the longer-term PCE degradation, TCE appears to be fluctuating with some increase. Also an expected increase in the daughter product cis-DCE was observed (Table 3). As Figure 2 shows, no significant increases in aqueous phase chlorinated ethenes have occurred following the 3DMe application and sequential reductive dechlorination is commencing as indicated by increases in the daughter products TCE, cis-DCE and VC. Ethene concentrations appear to be increasing ever so slowly indicating successful, complete dechlorination.

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Advanced Technologies for Groundwater Resources

3-D MicroemulsionTM Effective in Treating CVOC Contamination

SITE SUMMARY

3-D Microemulsion (3DMe)TM, a form of HRC Advanced[®], was used to treat chlorinated volatile organic compounds (CVOCs) at a manufacturing facility in Florida. 3DMe was injected around wells MW-103 and MW-106 to reduce tetrachloroethene (PCE) and trichloroethene (TCE) concentrations. Prior to injection, PCE and TCE levels had exceeded 2,000 micrograms per liter (ug/L) and 160 ug/L, respectively. Cis-1,2dichloroethene (DCE) was present at approximately 38 ug/L.

TECHNOLOGY DESCRIPTION

3DMe is composed of free lactic acid, controlled-release lactic acid (polylactate) and certain fatty acid components which are esterified to a carbon backbone molecule of glycerin. When injected into contaminated soil and groundwater, 3DMe produces a sequential, staged release of its electron donor components. The immediately available free lactic acid is fermented rapidly while the controlled-release lactic acid is metabolized at a more controlled, gradual rate. The fatty acids are converted to hydrogen over a mid-to long-range timeline giving 3DMe an exceptionally long electron donor release profile. This staged fermentation provides an immediate, mid-range and very long-term, controlled-release supply of hydrogen (electron donor) to fuel the reductive dechlorination process.

REMEDIATION APPROACH

- Remediation Objective: Through a pilot test, show the effectiveness of 3DMe to reduce CVOC concentrations.
- > Application Type: Direct-Injection
- Product: 3-D Microemulsion
- ➤ Quantity Applied: 1,080 lbs
- > Application Rate: 5.0 lbs/ft
- ➤ Injection Spacing: 5.0 ft

SITE CHARACTERISTICS

General

- Name: Sherwood Medical
- Location: Deland, FL
- Industry: Manufacturing
- Contaminants of Concern:

Contaminant	Concentration	
PCE	2,300 ug/L	
TCE	160 ug/L	
cis-1,2-DCE	38 ug/L	
VC	ND	

Hydrogeology

Treatment Area: MW-103: ~300 ft²

MW-106~300 ft²

Soil Type: Silty Sand

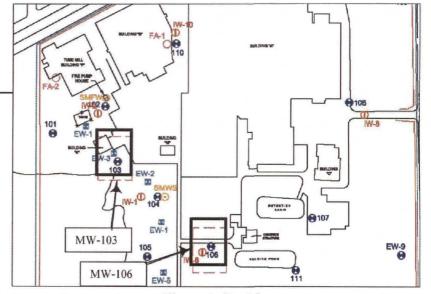
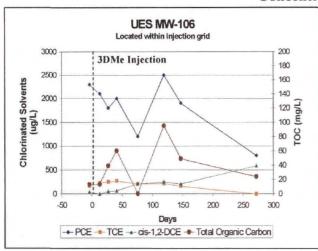
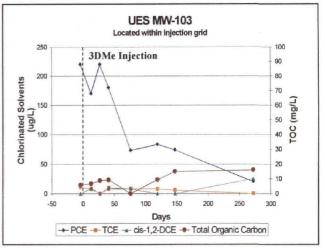


Figure 1. Site Map

Concentrations vs. Time





CONCLUSION

Two monitoring wells were used in this pilot test, MW-106 and MW-103. Well MW-106 contained pre-treatment PCE concentrations of 2,300 ug/L. At 272 days post-3DMe injection, PCE was reduced to 800 ug/L, while TCE levels were reduced to non-detect concentrations. Total organic carbon (TOC) levels remain elevated and 3DMe appears to be working well into the first year following application. Daughter products such as DCE have increased slightly as the reductive dechlorination process proceeds.

Monitoring well MW-103 started with lower CVOC concentrations and also showed a significant reduction in PCE. Concentrations over the 272 day period were reduced from 220 ug/L to 20 ug/L, a 91% reduction.

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Advanced Technologies for Groundwater Resources

3-D Microemulsion (3DMe)™ INSTALLATION INSTRUCTIONS

High-Volume, Wide-Area, Micro-Emulsion Application

Introduction

3-D Microemulsion (3DMe)TM, a form of HRC Advanced[®], should <u>ONLY</u> be applied as a high-volume, micro-emulsion. In this form it offers greater physical distribution of the 3DMe material across a larger potential radius from a single injection point. The production of a 3DMe emulsion involves the on-site, volumetric mixing of 10 parts water with 1 part delivered 3DMe concentrate to form the injection-ready 3DMe micro-emulsion. This micro-emulsion suspension can then be injected directly or further diluted to a predetermined ratio of 3DMe to water. The following instructions provide details in the production and installation of the 3DMe micro-emulsion.

Material Overview Handling and Safety

3DMe concentrate is shipped and delivered in 4.25-gallon buckets. Each bucket has a gross weight of approximately 32 pounds. Each bucket contains 30 pounds of 3DMe concentrate (net weight) and a nominal volume of 3.7 gallons. At room temperature, 3DMe concentrate is a liquid material with a viscosity of approximately 500 centipoise, roughly the equivalent of pancake syrup. The viscosity of 3DMe is not temperature sensitive above 50 °F (10 °C). However, below 50 °F the viscosity may increase significantly. If the user plans to apply the product in cold weather, consideration should be given to heating the material to above 60 °F so that it can be easily handled. 3DMe concentrate should be stored in a warm, dry place that is protected from direct sunlight. It is common for stored 3DMe concentrate to settle somewhat in the bucket, a quick pre-mix stir by a hand held drill with a paint or "jiffy mixer" attachment will rapidly re-homogenize the material. 3DMe concentrate is non-toxic, however field personnel should take precautions while handling and applying the material. Field personnel should use appropriate personal protection equipment (PPE) including eye protection. Gloves should be used as appropriate based on the exposure duration and field conditions. A Material Safety Data Sheet is provided with each shipment. Personnel who operate field equipment during the installation process should have appropriate training, supervision, and experience and should review the MSDS prior to site operations.

Micro-Emulsion Production 3DMe to Water Ratio

3DMe concentrate should be mixed with water on a volume to volume (v/v) basis to produce a micro-emulsion starting at 10 parts water: 1 part 3DMe. Although micro-emulsions can be easily produced using greater water volumes than 10 parts, e.g. 20 to 50 parts water to 1 part 3DMe, the initial micro-emulsion should never be produced below a ratio of less than 10 parts water: 1 part 3DMe v/v. WARNING: Do not attempt to produce a micro-emulsion at less than 10 parts water to 1 part 3DMe ratio v/v. This will produce an undesirable and unstable solution.

The field production of 3DMe micro-emulsion is a very simple procedure; however, it is critical that the user follow the mixing directions outlined below. Never attempt to add water to the 3DMe as this will produce an undesirable and unstable large emulsion. Always add the 3DMe to a large volume of water.

As indicated previously the 10:1 ratio of water to 3DMe v/v is the minimum water ratio that can be used, a greater ratio (more dilute solution) can easily be achieved and is governed by: A) the volume of 3DMe required to treat the estimated contaminant mass, B) the pore volume in which the material is applied, C) the time available for installation (gallons/pump rate), and C) the estimated volume of 3DMe micro-emulsion that the target zone will accept over the time period allocated for installation.

Conceptually, although a higher volume of water to volume of 3DMe will produce a larger volume of the suspension, it will lower the concentration of 3DMe per gallon of solution. Thus, the benefit of using a high water/3DMe v/v ratio in order to affect a greater pore volume of the subsurface aquifer is offset by the dilution of the 3DMe per unit volume of suspension as well as by the limitations of the subsurface hydraulic conductivity and effective porosity (capacity of the aquifer to accept the volume of 3DMe micro-emulsion).

It is important that the user plan in advance the v/v 3DMe/water ratio to be employed at a project site. The resulting volume of solution will dictate the site water requirements and the time required for injection, etc. If upon injection of greater than 10:1 3DMe micro-emulsion, the subsurface does not readily accept the volume of solution as designed, the user can adjust downward the v/v water to 3DMe ratio until a more concentrated suspension is produced (this solution should never drop below the required 10 parts water:1 part 3DMe v/v production ratio). For more information on designing a 3DMe/water ratios to meet specific site conditions, please contact Regenesis Technical Services.

Direct Push Application Requirements

One of the best methods to deliver the 3DMe micro-emulsion into the subsurface is to pressure inject the solution through direct-push rods using hydraulic equipment, or to pressure inject/gravity feed the micro-emulsion into the dedicated injection wells. The use of low cost push points or temporary injection points allows the applier to more cost effectively distribute the 3DMe material across shallow sites by employing multiple points per site. In the case of treating deep aquifer sites, the use of the micro-emulsion applied via dedicated injection wells is likely to be the most cost effective remediation approach. Please note that this set of instructions

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is specific to direct-push equipment. Please contact Regenesis Technical Services to assist you with dedicated injection well applications.

In general, Regenesis strongly recommends application of the 3DMe micro-emulsion using an injection pump with a minimum delivery rate of three gallons per minute (gpm) and a pressure rating of between 150 to 200 pounds per square inch (psi). Note: the injection pump requirements are different than the requirements of the mixing pump (see Mixing to Generate 3DMe Micro-emulsion). High pressure, positive displacement pumps and progressive cavity pumps are appropriate for injecting 3DMe. For low permeability lithologies (clay, silt) higher pressure pumps (800-1600 psi) may be necessary, while for more permeable lithologies (gravel, sand) a lower pressure pump may be adequate. Examples of appropriate pumps are: Rupe Models 6-2200, 9-1500 and 9-1600 (positive displacement), Geoprobe GS-2000 (positive displacement) and DP-800 (progressive cavity), Yamada (air diaphragm), Moyno (progressive cavity), and Wilden (air diaphragm). Delivery rate is a critical factor in managing installation time and costs. Generally, higher delivery rates (>6 gpm) are more cost effective for these types of applications but pump selection should be on a site specific basis and account for the volume of 3DMe solution and specific aquifer conditions present at the site.

The installation of the 3DMe micro-emulsion should span the entire vertical contaminated saturated thickness. If the vertical extent of the application is confined to a limited interval, then the micro-emulsion should be placed across a vertical zone extending a minimum of one-foot above and one-foot below the screened interval of monitoring wells that are being used to evaluate the performance of the project.

Producing the 3DMe Micro-Emulsion

The application of 3DMe requires the creation of a micro-emulsion. Technically the optimal suspension is an 3DMe-in-water suspension containing micro-emulsions. Before beginning the mixing procedure the user should have in mind the desired water to 3DMe ratio v/v desired.

It is critical that the micro-emulsion be produced using a high-shear apparatus such as a high speed centrifugal pump. The shearing provided by the vanes in these types of pumps is sufficient to form and maintain a homogeneous milky emulsion. This pump will be a different pump than that used to inject the 3DMe micro-emulsion into the subsurface. If the user is uncertain as to requirements for the pump or the applicability of a certain pump, please contact Regenesis Technical Services. Regenesis typically suggests using a water trailer/pump apparatus commonly found at equipment rental facilities. Regenesis recommends using a Magnum Products LLC model MWT500 or equivalent water trailer (fitted with centrifugal recirculation pump). This "trash pump" or transfer pump is an ideal high shear pump and the water tank (400 gallons) serves as an excellent mixing tank.

To ensure that proper micro-emulsion suspension is generated Regenesis suggests a two-step process that simply requires mixing at least 10 parts water to 1 part 3DMe concentrate using water at a temperature $\geq 60^{\circ}F$.

Step 1) Regenesis recommends that the 3DMe concentrate in each bucket be rehomogenized using a drill equipped with a paint or "jiffy" mixer attachment as minor settling may have occurred during shipment.

Step 2) to calculate the volume of water necessary to produce a 10:1 v/v micro-emulsion, each bucket of 3DMe concentrate containing 3.7 gallons of material should be mixed with 37 gallons of water.

Example: 6 buckets x 3.7 gallons 3DMe concentrate/bucket yields a total of 22.2 gallons of 3DMe concentrate. Thus, a 10:1 v/v solution will require 222 gallons of water (22.2 gallons 3DMe concentrate x 10 gallons water yields 222 gallons of water). A nominal total volume micro-emulsion would result from the summation of the 3DMe concentrate volume (22.2 gallons) and the water volume (222 gallons). This yields a total fluids delivery volume of approximately 244 gallons.

The previously calculated water volume (222 gallons) should be transferred into an appropriately sized mixing tank. The water should be circulated by the high shear centrifugal pump and each of the six 3DMe buckets slowly poured into the tank. Each bucket of 3DMe concentrate should be poured at a slow rate (approx. 1 minute per bucket) and the contents of the tank continually recirculated using the high hear centrifugal pump. A period of 1-2 minutes should be allowed between addition of each subsequent bucket of 3DMe concentrate to allow the centrifugal pump to continue to shear and mix the water/3DMe concentrate. Upon addition of the entire volume of 3DMe concentrate the pump should remain on to allow the solution mixture to recirculate. The recirculation of the 3DMe micro-emulsion should continue until the material is injected to maintain micro-emulsion consistency.

Application of Micro-Emulsion Using Direct-Push Methods

- Prior to the installation of the micro-emulsion, any surface or overhead impediments should be identified as well as the location of all underground structures. Underground structures include but are not limited to: utility lines, tanks, distribution piping, sewers, drains, and landscape irrigation systems.
- 2) The planned installation locations should be adjusted to account for all impediments and obstacles.
- 3) Pre-mark the installation locations, noting any points that may have different vertical application requirements or total depth.
- 4) Set up the direct-push unit over each specific point and follow the manufacturer's standard operating procedures (SOP). Care should be taken to assure that probe holes remain vertical.
- 5) For most applications, Regenesis suggests using drive rods with an O.D. of at least 1.25-inches and an I.D. of at least 0.625-inches I.D (Geoprobe or equivalent). However, the lithologic conditions at some sites may warrant the use of larger 2.125-inch O.D./1.5-inch I.D. drive rods.

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- 6) The most typical type of sub-assembly currently being used is designed for 1.25-inch direct-push rods and is manufactured by Geoprobe. Other brands of drive rods can also be used but require the fabrication of a sub-assembly that allows for a connection between the pump and drive rod.
- 7) For mixing large volumes of the micro-emulsion, Regenesis recommends using a Magnum Products LLC model MWT500 water trailer (fitted with centrifugal recirculation pump) or equivalent unit. However, single large volume poly tanks are adequate. We suggest filling the tank with an appropriate quantity (e.g. from the example above 222 gallons) of water before start of mixing operations. The tank should be configured so that both a hose and a fire hydrant or larger water tank can be connected to it simultaneously and filled with water quickly and easily. This will dramatically reduce the time needed to fill the tank with mixing water.
- 8) Regenesis highly recommends preparing the micro-emulsion before pushing any drive rods into the subsurface. NOTE: it is best if the micro-emulsion is produced a single day application volumes.
- 9) After the micro-emulsion mixing/shearing step has been completed as described above, the micro-emulsion is ready to be applied. Check to see if a hose has already been attached to the inlet side of the centrifugal pump. If this has not been done, do so now.
- 10) If a non-water trailer tank is being used for mixing the micro-emulsion a stand alone centrifugal pump and hose system should be used for the shearing and mixing operations.
- 11) Advance drive rods through the ground surface, as necessary, following SOP.
- 12) Push the drive rod assembly with an expendable tip to the desired maximum depth. Regenesis suggests pre-counting the number of drive rods needed to reach depth prior to starting injection activities to avoid any miscalculations.
- 13) After the drive rods have been pushed to the desired depth, the rod assembly should be withdrawn three to six inches. The expendable tip can be dropped from the drive rods, following SOP.
- 14) If an injection tool is used instead of a direct-push rod with an expendable tip, the application of material can take place without any preliminary withdrawal of the rods.
- 15) In some cases, introduction of a large column of air may be problematic. This is particularly the case in deep injections (>50 ft) with large diameter rods (>1.5-inch O.D.). To prevent the injection of air into the aquifer during the application, fill the drive rods with 3DMe emulsion after they have been pushed to the desired depth and before the disposable tip has been dropped or before the injection tip is operational.

- 16) Transfer the appropriate quantity of the micro-emulsion from the water trailer to the working/application pump hopper or associated holding tank.
- 17) A volume check should be performed prior to the injection of the micro-emulsion. Determining the volume discharged per unit time/stroke using a graduated bucket and stopwatch or stroke counter.
- 18) Start the pump and use the graduated bucket to determine how many gallons of microemulsion are delivered each minute or stroke per unit volume.
- 19) Connect the 1.25-inch O.D., 1-inch I.D. delivery hose to the pump outlet and the appropriate sub-assembly. Circulate the micro-emulsion through the hose and the sub-assembly to displace any air present in the system.
- 20) Connect the sub-assembly to the drive rod. After confirming that all of the connections are secure, pump the micro-emulsion through the delivery system to displace any water or other fluids in the rods.
- 21) The pump engine RPM and hydraulic settings should remain constant throughout the day to maintain a constant discharge rate.
- 22) The material is now ready to be installed in the subsurface. Use the pumps discharge rate as calculated in step 18 to determine the withdrawal rate of the drive rods needed for the application.
- 23) Slowly withdraw the drive rods using Geoprobe Rod Grip or Pull Plate Assembly (Part AT1222-For 1.25-inch drive rods). While slowly withdrawing single lengths of drive rod (three or four feet), pump the pre-determined volume of micro-emulsion into the aquifer across the desired treatment interval.
- 24) Remove one or two sections of the drive rod at a time. The drive rod may contain some residual material so Regenesis suggests placing it in a clean, empty bucket and allowing the material to drain. Eventually, the material recovered in the bucket should be returned to the pump hopper for reuse.
- 25) Observe any indications of aquifer refusal such as "surfacing" around the injection rods or previously installed injection points. If aquifer acceptance appears to be low, allow enough time for the aquifer to equilibrate prior to removing the drive rod.
- 26) Repeat steps 19 through 25 until treatment of the entire contaminated vertical zone has been achieved.
- 27) Install an appropriate seal, such as bentonite, above the micro-emulsion injection zone. The seal should span across the entire vadose zone. Depending on soil conditions and local regulations, a bentonite seal using chips or pellets can be used. If the injection hole remains open more than three or four feet below the ground surface sand can be used to fill the hole and provide a base for the bentonite seal. The installation of an appropriate seal assures that

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3DMe Install Instructions, Updated 040607 CS
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the micro-emulsion remains properly placed and prevents contaminant migration from the surface. If the micro-emulsion continues to "surface" up the direct-push borehole, an oversized disposable drive tip or wood plug/stake can be used to temporarily plug the hole until the aquifer equilibrates and the material stops surfacing.

- 28) Remove and clean the drive rods as necessary.
- 29) Finish the borehole at the surface as appropriate (concrete or asphalt cap, if necessary).
- 30) Periodically compare the pre- and post-injection discharge rates of the micro-emulsion in the pump hopper or holding tank using any pre-marked volume levels. If volume level indicators are not on the pumps hopper or holding tank use a pre-marked dipstick or alternatively temporary mark the hopper or holding tank with known quantities/volumes of water using a carpenter's grease pencil (Kiel crayon).
- 31) Move to the next probe point, repeating steps 11 through 29.

Helpful Hints

1) Application in Cold Weather Settings

As discussed in the Material Overview, Handling, and Safety section, cold weather tends to increase the viscosity of 3DMe as well as decrease the ease of micro-emulsion formation. To optimize an application in cold weather settings Regenesis recommends maintaining the 3DMe concentrate and the associated water at a temperature $\geq 60^{\circ}F$ (16°C). The following procedures can be used to facilitate the production and installation of a 10:1 v/v 3DMe micro-emulsion.

- Raise and maintain the temperature of the HRC-A to at least 60°F (16°C) prior to mixing with water. A hot water bath can be used to heat up the 3DMe concentrate buckets. A Rubbermaid fiberglass Farm Trough Stock Tank (Model 4242-00-GRAY) has been used for this process. This trough can hold up to 16 buckets of 3DMe concentrate.
- Hot water (approximately 130-170°F or 54-77°C) should be added to the tank after the buckets of 3DMe have been placed inside. The hot water should be delivered from a heated pressure washer (Hotsy® Model No. 444 or equivalent) or steam cleaner unit.
- It is equally critical that a moderate water temperature (>60°F or 16°C) be used in the production of the micro-emulsion. If on-site water supply is below 60°F use a hot water or steam cleaner to generate a small volume (e.g. 5-10% of total water volume) of hot water (130–170°F/54-77°C). This small volume of hot water should be added to remaining cold water volume to raise the total volume temperature to >60°F. When the 3DMe concentrate and water each reach a minimum temperature of 60°F or 16°C the two materials are ready for mixing.
- Upon achieving a minimum temperature of 60°F or 16°C (approximately 10-20 minutes). When the 3DMe and the associated water volumes have reached a minimum temperature of 60°F or 16°C (approximately 10-20 minutes) they are ready for mixing.
- In exceptionally harsh winter temperature settings use of a separate insulated pump containment structure and insulated delivery hoses may be necessary.

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- Use a pump with a heater unit.
- Periodically check the temperature of the material in the hopper.
- Re-circulate the 3DMe micro-emulsion through the pump and hose to maintain temperature adequate temperatures.
- Care should be taken to avoid the re-circulation of material volumes that exceed the volume of the pump hopper or holding tank.

Table 1: Equipment Volume and 3DMe Micro-Emulsion Weight per Unit Length of Hose (Feet)

Equipment	Volume	Product Weight
1-inch OD; 0.625-inch ID hose (10 feet)	0.2 gallon	1.6 lbs.
1.25-inch OD; 0.625-inch ID drive rod (3 feet):	0.05 gallon	0.4 lbs.
1.25-inch OD; 0.625-inch ID drive rod (4 feet):	0.06 gallon	0.5 lbs.

2) Pump Cleaning

For best results, use a heated pressure washer to clean equipment and rods periodically throughout the day. Internal pump mechanisms and hoses can be easily cleaned by re-circulating a solution of hot water and a biodegradable cleaner such as Simple Green through the pump and delivery hose. Further cleaning and decontamination (if necessary due to subsurface conditions) should be performed according to the equipment supplier's standard procedures and local regulatory requirements.

NOTE:

Before using the Rupe Pump, check the following:

- Fuel level prior to engaging in pumping activities (it would be best to start with a full tank)
- Remote control/pump stroke counter LCD display [if no display is present, the electronic counter will need to be replaced (Grainger Stock No. 2A540)]

Monitor pump strokes by observing the proximity switches (these are located on the top of the piston).

3) Bedrock Applications

When contaminants are present in competent bedrock aquifers, the use of direct-push technology as a delivery method is not possible. Regenesis is in the process of developing methods for applying 3DMe via boreholes drilled using conventional rotary techniques. To develop the best installation strategy for a particular bedrock site, it is critical that our customers call the Technical Services department at Regenesis early in the design process.

The micro-emulsion can be applied into a bedrock aquifer in cased and uncased boreholes. The micro-emulsion can be delivered by simply filling the borehole without pressure or by using a

single or straddle packer system to inject the material under pressure. Selection of the appropriate delivery method is predicated on site-specific conditions. The following issues should be considered in developing a delivery strategy:

- Is the aquifer's hydraulic conductivity controlled by fractures?
- Backfilling may be the better delivery method in massive, unfractured bedrock. This is particularly true in an aquifer setting with high permeability and little fracturing (such as that found in massive sandstone).
- Down-hole packer systems may be more advantageous in fractured bedrock aquifers.
 - In this case the fracture type, trends, and interconnections should be evaluated and identified.
- Are the injection wells and monitoring wells connected by the same fractures?
- Determine if it is likely that the injection zone is connected to the proposed monitoring points.
- If pressure injection via straddle packers is desired, consideration should be given to the well construction. Specific issues to be considered are:
 - Diameter of the uncased borehole (will casing diameter allow a packer system to be used under high pressures?).
 - Diameter of the casing (same as above).
 - Strength of the casing (can it withstand the delivery pressures?).
 - Length of screened interval (screened intervals greater than 10 feet will require a straddle packer system).

For further assistance or questions please contact Regenesis Technical Services at 949-366-8000.



ROBERTS ENVIRONMENTAL SERVICES. LL

APPENDIX C

Aerobic Injection Materials $(ORC^{\mathbb{B}})$



ORC A D V A N C E D[™]

"The Evolution of Controlled Release Oxygen"

ORC Advanced™ is the state-of-the-art technology for stimulating aerobic bioremediation. It offers unparalleled, maximum oxygen release for periods up to 12 months on a single injection and is specifically designed to minimize oxygen waste while maximizing contaminated site remediation.

HOW IT WORKS

Oxygen has been shown to be the limiting factor for microbes capable of aerobically degrading contaminants such as petroleum hydrocarbons.

Without adequate oxygen, contaminant degradation will either cease or may proceed by much slower anaerobic (oxygen-free) processes.

When hydrated, ORC Advanced is designed to release its full amount of oxygen (17% by weight) over a 12 month period. Upon injection into the subsurface, ORC Advanced utilizes its patented Controlled Release Technology (CRT™) to deliver its oxygen consistently over an extended period of time, avoiding excessive foaming and oxygen loss seen with commodity chemicals. This enables aerobic microbes to significantly accelerate rates of natural attenuation over long periods of time.

PRODUCT FEATURES AND BENEFITS

Highest Available Oxygen Content

More active oxygen (17%) plus Regenesis' patented CRT™ saves time and money by increasing degradation rates and improving remediation performance by providing more oxygen on a single injection. It is particularly effective at higher demand sites where oxygen may be limited and scavenged by competing carbon sources.

Patented Controlled Release Technology (CRT™)

Based on the same proven technology employed in the industry standard Oxygen Release Compound (ORC*), CRT allows for an efficient, long-term release of oxygen providing the optimal conditions for sustained aerobic biodegradation. This can save time and money by reducing the potential need for multiple applications. Also, oxygen release "lock-up" is avoided – an unfortunate problem experienced with commodity chemicals. (See Details of CRT in Figure 1).

In-Situ Application

Remediation with ORC Advanced is typically more cost-effective than ex-situ treatments. With the use of ORC Advanced there is minimal site disturbance with no above-ground piping or mechanical equipment, no operations and maintenance costs and no hazardous materials handling or disposal.

Free Technical Design and Support from Regenesis

Regenesis has been designing and evaluating *in-situ* accelerated bioremediation projects for over 10 years. This "free of charge" service offers the user the highest level of information available on stimulating natural attenuation and ensures a high level of project success.



Leaders in Accelerated Natural Attenuation



DEFINING THE SCIENCE BEHIND CONTROLLED RELEASE TECHNOLOGY (CRT™)

Early on, Regenesis researchers noted that in order to optimally stimulate the natural attenuation of aerobically degradable contaminants, biologically usable oxygen was best supplied in low but constant concentrations. Big bursts of oxygen are wasteful and simply "bubble off", often generating undesirable foaming and producing unwanted preferential flow paths in the subsurface. Regenesis sought to solve this problem by controlling the rate of oxygen release from solid oxygen sources.

The answer was provided by the development of CRT. The CRT process involves intercalating (embedding) phosphates into the crystal structure of solid peroxygen molecules. This patented feature, now available in the ORC Advanced^{**} formulation, slows the reaction that yields oxygen within the crystal, minimizing "bubble off" which can waste the majority of oxygen available in common solid peroxygen chemicals.

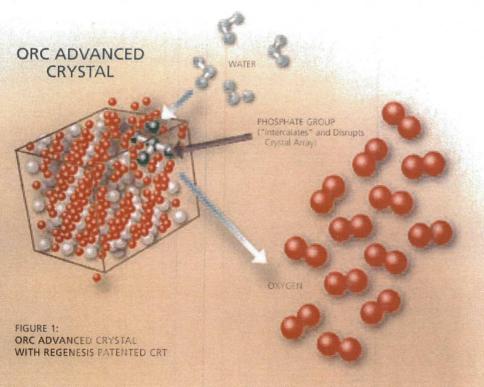
CRT[™] provides "balance" – it slows down the rate of oxygen release while at the same time preventing "lock-up". Commodity solid peroxygen chemicals, when in contact with water, will produce an initial rapid and uncontrolled release of oxygen. Then, as hydroxides form, a significant portion of the oxygen deeper in the crystal is made unavailable or becomes "locked up." This undesirable effect is inefficient and costly. CRT prevents lock up and controls the rate of oxygen release, representing the state-of-the-art technology in passive oxygen delivery.

CRT Specifics

Uniformly embedded within the crystalline structure of the peroxygen are phosphate ions. These ions do two important things:

- 1. they slow the rate of hydration that liberates oxygen thereby creating the CRT effect and
- 2. they form exit pathways for the oxygen in an otherwise tightly packed crystal that can become even more "locked-up" when hydroxides begin to form as a reaction by-product following oxygen liberation.

This patented process optimizes peroxygen performance and is only available in the Regenesis line of products.



For more information or a free project evaluation contact Regenesis at (949) 366-8000 or visit our website at www.regenesis.com



Leaders in Accelerated Natural Attenuation

ORC TECHNICAL BULLETIN #2.2.2.2

Oxygen Release Compound, ORC®

Uses in the Dual Phase Remediation of Chlorinated Hydrocarbous

Chlorinated hydrocarbons, such as PCE and TCE, are among the most recalcitrant environmental contaminants. Degradation mechanisms for these compounds are complex. While there is some evidence of aerobic breakdown, most of the metabolic pathways are anaerobic. Also, there may be dual-phase requirements for complete remediation to dechlorinated endpoints such that the process is initiated under anaerobic conditions and completed in the presence of oxygen. ORC can be used to complete remediation at the various oxygen-dependent stages.

ORC Can be Useful as Part of a Dual Phase Chlorinated Remediation

Phase 1

Anaerobic Degradation of PCE and TCE to DCE and VC

Phase 2

Aerobic (Co-metabolic or Substrate) Degradation of DCE and VC to CO2, HCL and H2O

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ORC TECHNICAL BULLETIN # 2.2.2.5

Oxygen Release Compound, ORC®

Vinyl Chloride Remediation Field Study

The enhanced bioremediation of vinyl chloride using ORC was demonstrated at an industrial site in Massachusetts. As part of the USEPA SITE program, ABB Environmental Services (now Harding Lawson Associates) conducted a dual phase treatment of a contaminant plume containing chlorinated hydrocarbons. The treatment took place in a recirculating well system as illustrated in Figure 1.

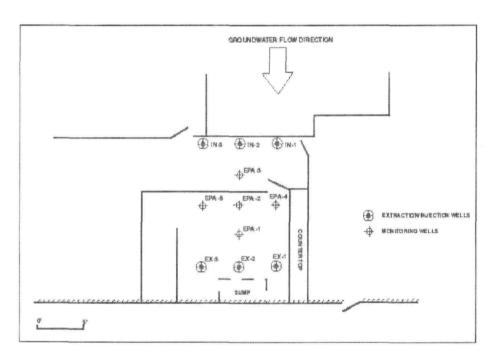


Figure 1

The first phase of treatment was the enhanced anaerobic biodegradation of the higher order chlorinated compounds (PCE and TCE) through the weekly addition of lactic acid. The products of the first phase of treatment, DCE and VC, were treated aerobically in the second phase. Aerobic conditions were maintained through the addition of ORC to the system. Results are presented in Figures 2 and 3. Following approximately 110 days of aerobic treatment with ORC, monitoring data averaged across IN-2, EPA-2, and EPA-3 indicated a 40% reduction in DCE and a 47% reduction in VC. Reductions at EPA-2 alone, at the center of the recirculating system, were 50% for DCE and 75% for VC. Cis-DCE epoxide, a transient biodegradation product, was detected, which is evidence showing that methane oxidizing bacteria were active and cis-DCE biodegradation was occurring.

As indicated in Figures 2 and 3, methane was added to the system during the middle of the aerobic treatment period in an effort to stimulate co-metabolic biodegradation. This step may have actually interfered with direct substrate remediation of DCE and VC.

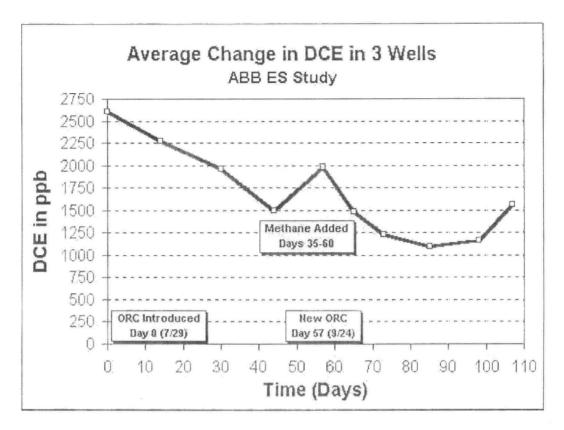


Figure 2

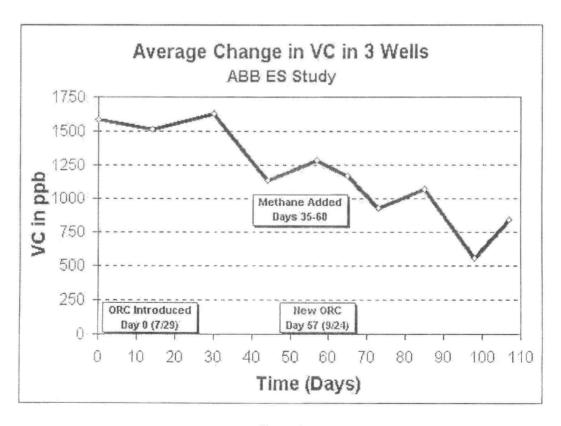


Figure J

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ORC TECHNICAL BULLETIN # 2.2.2.8

Oxygen Release Compound, ORC®

ORC Injection Vinyl Chloride Remediation

Introduction

Residual vinyl chloride concentrations have been remediated in the field at a mid-western site with ORC®. The site was formerly an aluminum coating facility that stored aromatic and chlorinated solvents in an underground storage tank (UST). The UST created a narrow plume in a prolific sandy aquifer less than twenty feet thick. The plume was approximately 350 ft. long by 40-60 ft, wide at the completion of the site investigation and prior to the start of remediation. Remediation of the solvent plume was completed in on-site areas. An off-site plume of vinyl chloride remained with dissolved concentrations just above generic residential clean-up criteria.

The rate of natural attenuation of vinyl chloride had stalled during the previous year and vinyl chloride reached the first sentinel well RL-5A in October 1997. At the same time, prior to treatment, the off-site vinyl chloride concentrations were between 2.4 to 37 parts per billion (ppb) over five locations.

The objectives were to complete the remediation of the off-site vinyl chloride with ORC through oxidation and enhancement of the indigenous bacteria to expedite vinyl chloride attenuation. Groundwater sampling results prior to and following injection of the ORC indicated a significant reduction of vinyl chloride concentrations within the first month in the treated areas. Rebound was observed downgradient of areas that did not receive full treatment.

The ORC project was tailored to the site's unique conditions that involved multiple contaminants, and other sources adjacent to the subject plume. In this instance, this technology provided a surgical tool to address contaminants within the plume without risking the hydraulic disturbance of contaminants from the unrelated areas. With the use of ORC, the regulators were able to approve the shut down of the advanced oxidation and SVE systems to reduce operational costs.

When ORC injection was initiated, only the off-site solvents plume remained for remediation. The wells impacted included RL-1A, RL-5A, and RL-7A. Unimpacted off-site wells included NW-5, MW-7, MW-9, and MW-10. This remaining impacted area, measured approximately 250 ft. long by 40 ft. at the time of ORC injection in March of 1998 (see Figure 1). Since the on-site area has been remediated only the off-site portion of the plume is shown on Figure 1. Off-site sources in and adjacent to the solvents plume included a former gasoline retail station, petroleum bulk storage area, and a former coal gasification facility. Mainly non-chlorinated petroleum compounds were associated with the off-site sources also remain comingled with the off-site vinyl chloride plume. These sources are located along the vinyl chloride plume or just to the east of the vinyl chloride plume shown on Figure 1. This co-mingling of non-chlorinated compounds in these areas was justification alone for the use of a non-invasive remedial technology.

In 1994 all parties historically involved with the on-site activities opted for generic residential clean-up criteria to eliminate future liabilities. These established remedial objectives included active remediation for only the on-site portion (source) of the solvent plume. The off-site dissolved plume was not initially targeted due to the co-mingled nature of the downgradient portion (off-site) of the solvents plume and the lack of involvement of the other parties in the clean-up.

During the site investigation it was determined that groundwater was encountered in medium sands at 13 to 19 feet (3.96 to 5.79 meters) and bounded on the bottom with a silty clay at approximately 30 feet (9.14 meters). The groundwater flow in this area is to the north-northwest at a velocity of 0.012 feet/day (4.2 x 10.7 cm/sec) with a nearly that gradient at the site.

Results

Active remediation of the site was initiated in the Fall of 1995. Closed loop soil vapor extraction was employed at the site in conjunction with advanced oxidation of the dissolved solvent plume (subject plume) located on-site. During the operation of the remediation system groundwater was extracted downgradient of the source and highly oxygenated groundwater was reinjected upgradient of the dissolved plume. The groundwater system reduced dissolved concentrations on-site to less than generic residential criteria by April of 1997.

Direct injection of ORC was utilized within an area of residual vinyl chloride contamination found off-site. Based on the vertical, aerial extent of the plume, the ORC was injected with a grout pump and direct-push drilling technology within the vinyl chloride plume in grid with a roughly 12-5 foot spacing. Each boring was injected with the ORC slurry from the aquitard at the base of the aquifer to approximately one foot above the water table. STS Consultants utilized approximately twenty-five percent more ORC that recommended by Regenesis.

The ORC injection was performed in March of 1998. Based on the results as presented on Table 1 the monthly groundwater results (per EPA Method 8260) have shown attenuation (beginning in the first month). The results suggest that it is feasible to remediate vinyl chloride in the field by delivering oxygen to the saturated zone. In areas with adequate spacing for ORC addition (ie. RL-5A), complete remediation of vinyl chloride was observed within three to four months. Table 1 shows the vinyl chloride concentrations in the wells located off-site prior to and following treatment.

The monthly analytical results indicate that these areas have attenuated at an accelerated rate since addition of ORC. Rebound was observed after four months in areas monitored immediately downgradient of untreated areas. The right of way associated with RL-1A and the roadway associated with RL-7A are the primary areas not treated in the first phase of ORC injection. At this time the sentinel well is consistently below generic residential criteria for vinyl chloride. Veasurement of dissolved oxygen in the monitor wells located along the spine of the plume indicates that the effectiveness of the magnesium peroxide at this site was limited to approximately three to four months, possibly due to impact from other known contaminant sources in the system.

Conclusion

The method of oxygenation was tailored to the existing site conditions, multiple contaminants, and orientation of sources adjacent to the subject plume. This technology provided a controlled means of remediating contaminants within the site's plume without the risk of hydraulteally influencing extrinsic contaminants from unrelated source areas. The use of this technology also facilitated regulatory approval to shut down the advanced oxidation system and the SVE system to reduce overall operational costs. The migration of the plume beyond the sentinel wells was effectively stopped.

Results suggest that spacing and the appropriate quantity of the ORC is important for success. Rebound occurred where planned spacing was not adhered to. The presence of roadways, buildings, and utility corridors, which precluded a uniform application, may have increased the amount of time required to remediate contaminants. Sparse placement of injection points and reduction of stoichiometrically sound quantities is not recommended.

It is important to remember that the primary focus of these activities was to remediate the plume and do this at a reasonable cost. This study did not therefore include bench studies, microbial population assays, or other ancillary field testing.

STS has recently reapplied ORC in December 1998 to the area in the same locations. This application has also included additional injection points in the roadway that bisects the body of the plume. The data will be evaluated in the months following the December 1998 treatment to further evaluate the effectiveness of this technology.

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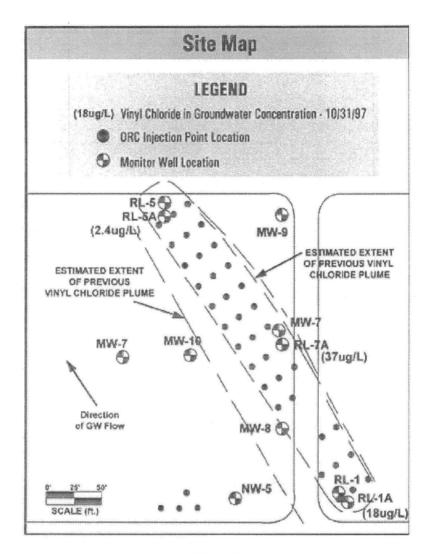


Figure 1

Date	RL-1A (ppb)	RL-5A (ppb)	RL-7A (ppb)
4/17/97	15	BQL	34
10/31/97	18	2.4	37
12/17/97	NS	5.0	NS
3/98	Inject ORC	Inject ORC	Inject ORC
4/15-16/98	5.0	BQL	24
5/18/98	BQL	BQL	13
6/24/98	BQL	BQL	BQL
7/23/98	6.0	BQL	20
8/21/98	BQL	BQL	BQL
9/25/98	BQL	BQL	6.0

Table I

Technical Bulletin Index||Regenesis Home Page

Oxygen Release Compound – Advanced (ORC AdvancedTM) MATERIAL SAFETY DATA SHEET (MSDS)

Last Revised: March 13, 2007

Section 1 - Material Identification

Supplier:



REGENESIS

1011 Calle Sombra San Clemente, CA 92673

Phone:

949.366.8000

Fax:

949.366.8090

E-mail:

info@regenesis.com

Chemical

A mixture of Calcium OxyHydroxide [CaO(OH)2] and

Description:

Calcium Hydroxide [Ca(OH)₂].

Chemical Family:

Inorganic Chemical

(ORC AdvancedTM)

Trade Name:

Advanced Formula Oxygen Release Compound

Chemical Synenyms

Calcium Hydroxide Oxide; Calcium Oxide Peroxide

Product

Used to remediate contaminated soil and groundwater

Use:

(environmental applications)

C	13	1	
Section	1	6 (1777)	position
has be to the the fine	AN/	ALCO NO COLD	[J. V. V. L. L. L. V. L.

CAS No. Chemical

682334-66-3 Calcium Hydroxide Oxide [CaO(OH)₂]

1305-62-0 Calcium Hydroxide [Ca(OH)₂]

7758-11-4 Dipotassium Phosphate (HK₂O₄P)

7778-77-0 Monopotassium Phosphate (H₂KO₄P)

Section 3 – Physical	Data	ivsical]	3	on	Sect
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Ferm:

Powder

Color:

White to Pale Yellow

Odor:

Odorless

Melting Point:

527 °F (275 °C) – Decomposes

Boiling Point:

Not Applicable (NA)

Flammability/Flash

Point:

NA

Auto- Flammability:

NA

Vapor Pressure:

NA

Self-Ignition

Temperature:

NA

Thermal

Decomposition:

527 °F (275 °C) – Decomposes

Bulk Density:

0.5 - 0.65 g/ml (Loose Method)

Solubility:

1.65 g/L @ 68° F (20° C) for calcium hydroxide.

Viscosity:

NA

pH:

11-13 (saturated solution)

Explosion Limits %

by Volume:

Non-explosive

Hazardous

Decomposition

Products:

Oxygen, Hydrogen Peroxide, Steam, and Heat

Hazardous

Reactions:

None

Section 4 – Reactivity Data

Stability:

Stable under certain conditions (see below).

Conditions to Avoid:

Heat and moisture.

Incompatibility:

Acids, bases, salts of heavy metals, reducing agents, and

flammable substances.

Hazardous

Polymerization:

Does not occur.

Section 5 - Regulations

TSCA

Inventory

Listed

List:

CERCLA Hazardous Substance (40 CFR Part 302)

Listed Substance:

No

Unlisted Substance:

Yes

Reportable Quantity

(RQ):

100 pounds

Characteristic(s):

Ignitibility

RCRA

Waste

D001

Number:

SARA, Title III, Sections 302/303 (40 CFR Part 355 - Emergency Planning and Notification)

Extremely

Hazardous

No

Substance:

SARA, Title III, Sections 311/312 (40 CFR Part 370 - Hazardous Chemical Reporting: Community Right-To-Know

Immediate Health Hazard

Hazard Category:

Fire Hazard

Threshold Planning

Quantity:

10,000 pounds

Section 5 – Regulations (cont)

SARA, Title III, Section 313 (40 CFR Part 372 - Toxic Chemical Release Reporting: Community Right-To-Know

Extremely

Hazardous

No

C

D

Substance:

WHMIS

Classification:

Oxidizing Material

Poisonous and Infectious

Material

Material Causing Other Toxic

Effects -

Eye and Skin Irritant

Canadian Domestic Substance List:

Not Listed

Section 6 - Protective Measures, Storage and Handling

Technical Protective

Measures

Storage:

Handling:

Keep in tightly closed container. Store in dry area, protected

from heat sources and direct sunlight.

Clean and dry processing pipes and equipment before operation. Never return unused product to the storage container. Keep away from incompatible products. Containers and equipment used to handle this product should be used

exclusively for this material. Avoid contact with water or

humidity.

Section 6 - Protective Measures, Storage and Handling (cont)

Personal	Protoct	ivo Ec	minmont	(DDE)
reisullai	Lintect	IVE LL	uibinent	(III)

Calcium Hydroxide

ACGIH® TLV® (2000)

 $5 \text{ mg/m}^3 \text{TWA}$

OSHA PEL

Engineering Controls:

Total dust-15 mg/m³ TWA

Respirable fraction-

 $5 \text{ mg/m}^3 \text{TWA}$

NIOSH REL (1994)

 5 mg/m^3

Respiratory Protection: For many conditions, no respiratory protection may be needed; however, in dusty or unknown atmospheres use a NIOSH

approved dust respirator.

Hand Protection:

Impervious protective gloves made of nitrile, natural rubbber

or neoprene.

Eye Protection:

Use chemical safety goggles (dust proof).

Skin Protection:

For brief contact, few precautions other than clean clothing are needed. Full body clothing impervious to this material should

be used during prolonged exposure.

Other:

Safety shower and eyewash stations should be present. Consultation with an industrial hygienist or safety manager for the selection of PPE suitable for working conditions is

suggested.

Industrial Hygiene:

Avoid contact with skin and eyes.

Protection Against

Fire & Explosion:

NA

		Section 7 - Hazards Identification
Emergency Overview:		Oxidizer – Contact with combustibles may cause a fire. This material decomposes and releases oxygen in a fire. The additional oxygen may intensify the fire.
Potential Effects:	Health	Irritating to the mucous membrane and eyes. If the product splashes in ones face and eyes, treat the eyes first. Do not dry soiled clothing close to an open flame or heat source. Any

Regenesis - ORC Advanced MSDS

clothing that has been contaminated with this product should

be submerged in water prior to drying.

High concentrations may cause slight nose and throat irritation with a cough. There is risk of sore throat and nose bleeds if Inhalation:

one is exposed to this material for an extended period of time.

Severe eye irritation with watering and redness. There is also Eve Contact:

the risk of serious and/or permanent eye lesions.

Irritation may occur if one is exposed to this material for Skin Contact:

extended periods.

Irritation of the mouth and throat with nausea and vomiting. Ingestion:

Section 8 - Measures in Case of Accidents and Fire

After

Spillage/Leakage/Gas

Leakage:

Collect in suitable containers. Wash remainder with copious quantities of water.

Extinguishing

Media:

See next.

Suitable:

Large quantities of water or water spray. In case of fire in close proximity, all means of extinguishing are acceptable.

Further Information:

Self contained breathing apparatus or approved gas mask should be worn due to small particle size. Use extinguishing media appropriate for surrounding fire. Apply cooling water to sides of transport or storage vessels that are exposed to flames until the fire is extinguished. Do not approach hot vessels that

contain this product.

First Aid:

After contact with skin, wash immediately with plenty of water and seap. In ease of contact with eyes, rinse immediately with plenty of water and seek medical attention. Consult an opthalmologist in all cases.

Section 8 - Measures in Case of Accidents and Fire

Eye Contact:

Flush eyes with running water for 15 minutes, while keeping the cyclids wide open. Consult with an ophthalmologist in all cases.

Inhalation:

Remove subject from dusty environment. Consult with a physician in case of respiratory symptoms.

Regenesis - ORC Advanced MSDS

Ingestion:

If the victim is conscious, rinse mouth and admnister fresh water. DO NOT induce vomiting. Consult a physician in all cases.

Skin Contact:

Wash affected skin with running water. Remove and clean clothing. Consult with a physician in case of persistent pain or redness.

Special Precautions:

Evacuate all non-essential personnel. Intervention should only be done by capable personnel that are trained and aware of the hazards associated with this product. When it is safe, unaffected product should be moved to safe area.

Specific Hazards:

Oxidizing substance. Oxygen released on exothermic decomposition may support combustion. Confined spaces and or containers may be subject to increased pressure. If product comes into contact with Hammables, the or explosion may occur.

Section 9 - Accidental Release Measures

Precautions:

Observe the protection methods cited in Section 3. Avoid materials and products that are incompatible with product. Immediately notify the appropriate authorities in case of reportable discharge (> 100 lbs).

Cleanup Methods:

Collect the product with a suitable means of avoiding dust formation. All receiving equipment should be clean, vented, dry. labeled and made of material that this product is compatible with. Because of the contamination risk, the collected material should be kept in a safe isolated place. Use large quantities of water to clean the impacted area. See Section 12 for disposal methods.

Section 10 - Information on Toxicology

Toxicity Data

Oral Route, LD₅₀, rat, > 2,000 mg/kg (powder 50%)

Acute Toxicity:

Dermal Route, LD₅₀, rat, > 2,000 mg/kg (powder 50%)

Inhalation, LD₅₀, rat, $> 5,000 \text{ mg/m}^3$ (powder 35%)

Irritation:

Rabbit (eyes), severe irritant

Regenesis - ORC Advanced MSDS

Sensitization:

No data

Chronic Toxicity:

In vitro, no mutagenic effect (Powder 50%)

Target

Organ

Effects:

Eyes and respiratory passages.

Section 11 - Information on Ecology

Ecology Data

 $10 \text{ mg Ca}(OH)_2/L$: pH = 9.0

 $100 \text{ mg Ca}(OH)_2/L$: pH = 10.6

Acute Exotoxicity:

Fishes, Cyprinus carpio, LC₅₀, 48 hrs, 160 mg/L

Crustaceans, Daphnia sp., EC₅₀, 24 hours, 25.6 mg/L

(Powder 16%)

Mobility:

Low Solubility and Mobility

Water - Slow Hydrolysis.

Degradation Products: Calcium Hydroxide

Abiotic Degradation:

Water/soil – complexation/precipitation. Carbonates/sulfates

present at environmental concentrations.

Degradation products: earbonates/sulfates sparingly soluble

Biotic Degradation:

NA (inorganic compound)

Potential for

Bioaccumulation:

NA (ionizable inorganic compound)

Section 11 - Information on Ecology (cont)

Observed effects are related to alkaline properties of the product. Hazard for the environment is limited due to the product properties of:

Comments:

No bisaccumulation

Weak solubility and precipatation as carbonate or sulfate in an aquatic environment.

Diluted product is rapidly neutralized at environmental pH.

Further Information: NA

		Section 12 - Disposal Considerations	
Waste Method:	Disposal	Consult current federal, state and local regulations regarding the proper disposal of this material and its emptied containers.	
	Sec	tion 13 - Shipping/Transport Information	
D.O.T Name:	Shipping	Oxidizing Solid, N.O.S [A mixture of Calcium OxyHydroxide [CaO(OH) ₂] and Calcium Hydroxide [Ca(OH) ₂].	
UN Numbe	er:	1479	
Hazard Cl	ass:	5.1	
Label(s):	Label(s): 5.1 (Oxidizer)		
Packaging	Group:	II	
STCC Number: 4918717		4918717	
***************************************		Section 14 - Other Information	

Section 14 - Other Information			
HMIS" Rating	Health — 2 Flammability — 0	Reactivity – 1 PPE - Required	
HMIS® is a registere	d trademark of the Natio	nal Painting and Coating Association.	
NFPA® Rating	Hearth – 2 Flammability – 0	Reactivity – I OX	
NFPA [®] is a registere	d trademark of the Natio	nal Fire Protection Association.	
Reason for Issue:		Update texicological and ecological data	

Section 15 - Further Information

The information contained in this document is the best available to the supplier at the time of writing, but is provided without warranty of any kind. Some possible hazards have been determined by analogy to similar classes of material. The items in this document are subject to change and clarification as more information become available.

APPENDIX D

Soil Vapor Extraction (SVE)/ Air Sparging (AS)
[Double-sided documents]

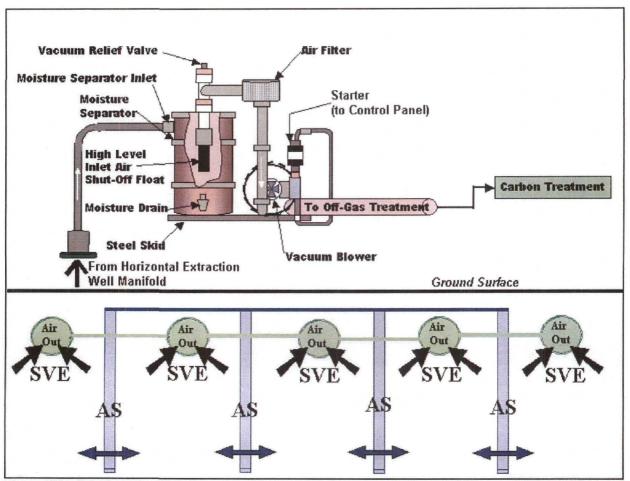
DIRECTION & SUPERVISION OF PROFESSIONAL ENGINEER

From Page 3, paragraph #16, of the Voluntary Remediation Agreement (VRA) executed by Geocel Corporation and IDEM, "...should the work require a designed remediation system or engineered barrier, the work will be done under the direction and supervision of a Professional Engineer with expertise in hazardous substance or petroleum site investigation and remediation."

I, **Richard J. Fulk**, am a Professional Engineer (P.E.) licensed to practice in the State of Indiana. I also have experience designing and implementing remediation systems at hazardous substance and petroleum sites. The proposed soil vapor extraction (SVE)/air sparging (AS) systems at the Geocel Corporation VRP site in Elkhart, Indiana, were designed under my direction and supervision.

Signature:	Pulm / Tulk, P. E.	
Date:	26 Aug 2008	
	HILLIAND J. FUR PROSTERES POLITICAL	
	No. PE60860049 STATE OF WOIANA WOIAN	
Seal:	WOIANA GREATHING	

GEOCEL CORP. (VRP#6070601) TYPICAL SVE/AS SYSTEM LAYOUT



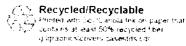
Modified from: FRTR – Federal Remediation Technologies Roundtable. Remediation Technologies Screening Matrix & Reference Guide, Version 4.0 (http://www.frtr.gov/matix2/top_page.html)

Abstracts of Remediation Case Studies



Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable



Abstracts of Remediation Case Studies

Volume 1

Prepared by Member Agencies of the Federal Remediation Technologies Roundtable

Environmental Protection Agency Department of Defense

U.S. Air Force

U.S. Army

U.S. Navy

Department of Energy

Department of Interior

National Aeronautics and Space Administration

Tennessee Valley Authority

Coast Guard

March 1995

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This document has been subjected to administrative review by Agencies participating in the Federal Remediation Technologies Roundtable, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Further information on the Roundtable may be obtained from the Chairman at EPA's Technology Innovation Office at (703) 308-8800.

FOREWORD

This report is a collection of abstracts summarizing 37 case studies of site remediation projects prepared by Federal agencies. The case studies were undertaken to document the results and lessons learned from early technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of cleanup technologies. The case studies were collected under the auspices of the Federal Remediation Technologies Roundtable as part of a larger effort to improve future project documentation and information transfer.

The Roundtable was created to exchange information on site remediation technologies, and to consider cooperative efforts that could lead to a greater application of innovative technologies. Roundtable member agencies, including the U.S. Environmental Protection Agency, U.S. Department of Defense, and U.S. Department of Energy, expect to complete many site remediation projects in the near future. These agencies recognize the importance of documenting the results of these efforts, and the benefits to be realized from greater coordination.

The case study reports themselves are organized by technology in a four-volume set listed below. In the future, the set will grow through periodic supplements tracking additional progress with site remediation.

Remediation Case Studies: Bioremediation (PB95-182911); Remediation Case Studies: Groundwater Treatment (PB95-182929); Remediation Case Studies: Soil Vapor Extraction (PB95-182937); and Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification (PB95-182945).

Four Volume Set: Remediation Case Studies (PB95-182903).

To order, call the National Technical Information Service at (703) 487-4650 or write them at the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161.

Walter W. Kovalick, Jr., Ph.D. Chairman Federal Remediation Technologies Roundtable

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4.0 REMEDIATION CASE STUDIES: SOIL VAPOR EXTRACTION

Soil Vapor Extraction System at Commencement Bay,	
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Battle Creek, Michigan80)

Soil Vapor Extraction System at Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, Washington

Site Name: Commencement Bay, South Tacoma Channel (Well 12A) Superfund Site	Contaminants: Chlorinated Aliphatics trans-1,2-Dichloroethene (DCE), 1,1,2,2-Tetrachloroethane (PCA), 1,1,2,2-Tetrachloroethene (PCE), Trichloroethene (TCE)	Period of Operation: Status: Ongoing Report covers - 8/92 to 2/94
Location: Tacoma, Washington	 Average VOC concentrations in top 25 feet of soil ranged from 10 to 100 mg/kg Average PCA concentrations in soil borings ranged from 6,200 at 30 feet depth to over 19,000 mg/kg at 40 feet depth Approximately 571,000 lbs of VOCs present in unsaturated zone 	Cleanup Type: Full-scale cleanup (Report documents demonstration phase)
Vendor: Environmental Science & Engineering, Inc.	Technology: Soil Vapor Extraction - 22 wells used for vapor extraction, air inlet, and observation - Vapor-phase carbon adsorption (GAC)	Cleanup Authority: CERCLA, Local Requirements - ROD Date: 3/85
SIC Code: 2851 (Paints, Varnishes, Lacquers, Enamels, and Allied Products)	used for treatment of extracted VOCs - GAC beds regenerated on site with low pressure steam - Design flow rate for extraction system of 3,000 standard cubic feet per minute (scfm)	Point of Contact: Phil Stoa Remedial Project Manager U.S. Army Corps of Engineers Seattle District
Waste Source: Storage - Drums; Other: Pour off from Processing Tanks	Type/Quantity of Media Treated: Soil - Volume of contaminated soil reported as 98,2 of 66,300 ft ² and a depth of 40 ft	03 cubic yards, based on an area
Purpose/Significance of Application: Application of soil vapor extraction with an on-site solvent recovery system; relatively large volume of contaminated soil; possible presence of separate liquid phases of VOCs and tar-like compounds in soil.	 Upper aquifer (50 ft thickness) consists of unc Surface soil permeability ranges from 2.8 to 3 Separate liquid phases of VOCs in soil and gr Tar-like compounds in soil suspected 	3.6 x 10 ⁻³ cm/sec
Regulatory Requirements/Cleanup Go - No specific cleanup goals identified		

- Local permit required for air emissions
- Performance objective for air treatment system set at 99% removal
- Air discharge limits specified as follows:
 - **PCA** 0.149 lbs/hr
 - **PCE** 0.095 lbs/hr
 - 0.344 lbs/hr

Soil Vapor Extraction System at Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, Washington (Continued)

Results:

- No results provided for quantity of contaminants removed during demonstration phase
- Computer modelling results show predicted removal rates for VOCs as a function of time
- Pilot-scale results indicated that 3 to 4 lbs/day/well of VOC could be removed from the upper 30 feet of soil
- No results provided for air emissions treatment system removals or mass discharge rates
- Problems were experienced with the operation of the solvent recovery system
- Condensed mixed solvents formed an emulsion which did not readily separate from the water

Cost Factors:

Total Capital Cost - \$5,313,973 (as of 5/94) (no breakdown of costs available)
Annual Operating Costs - \$100,000 (estimated) (no breakdown of costs available)

Description:

The Commencement Bay site was used from 1927 to 1964 for waste oil recycling, paint and lacquer thinner manufacturing, and solvent reclamation and hundreds of drums of material were stored at the site. Leaks from these drums, as well as the dumping of wastes directly on the ground and overflows from the solvent and waste oil recycling tanks, resulted in contamination of the soil and groundwater at the site. The primary contaminants of concern at the site included DCE (trans-1,2-dichloroethylene), PCA (1,1,2,2-tetrachloroethylene), PCE (1,1,2,2-tetrachloroethylene), and TCE (trichloroethylene). VOC soil concentrations range from 10 to 100 mg/L.

A full-scale SVE system was constructed in 1992. Operation testing of this system began in August 1992 and this report covers the demonstration phase of the project. The SVE system includes 22 vapor extraction wells. Granular activated carbon (GAC), used to treat extracted vapors, is regenerated on site using low pressure steam, which was subsequently condensed. The on-site solvent recovery system is used to separate VOCs from the condensate.

As of May 1994, the total capital costs and annual operating costs for this application were \$5,313,973 and \$99,810, respectively. While no performance data are available at this time, it was noted that the SVE system seems to be performing adequately. Several problems were experienced in the operation of the solvent recovery system. Condensed mixed solvents formed an emulsion which did not readily separate from the water. The report identifies a need to perform pilot testing of the solvent recovery system to ensure that separation of VOCs and water can be performed.

Soil Vapor Extraction at the Fairchild Semiconductor Corporation Superfund Site San Jose, California

Site Name: Fairchild Semiconductor Corporation Superfund Site	Contaminants: Chlorinated and Non-Chlorinated Aliphatics - TCA (trichloroethane), DCE (1,1- dichloroethene), IPA (isopropyl alcohol),	Period of Operation: January 1989 to April 1990
Location: San Jose, California	 xylenes, acetone, Freon-113, and PCE (tetrachloroethene) Maximum concentration of total solvents in soil was 4,500 mg/kg TCA - measured as high as 3,530 mg/kg in soil; xylenes as high as 141 mg/kg in soil 	Cleanup Type: Full-scale cleanup
Vendor: Dennis Curran Canonie Environmental Services Corporation 441 N. Whisman Road, Building 23 Mountain View, CA 94043 (415) 960-1640	Technology: Soil Vapor Extraction - 39 extraction wells, 2 vacuum pumps (capacity of 4,500 ft³/min at 20 inches of Hg) - Vapor treatment system - dehumidification unit and vapor phase	Cleanup Authority: CERCLA and State: California - ROD Date: 3/20/89 - PRP Lead
SIC Code: 3674 (Semiconductors and Related Devices)	granular activated carbon	Point of Contact: Belinda Wei U.S. EPA Region 9
Waste Source: Underground Storage Tank		75 Hawthorne Street San Francisco, CA 94105 (415) 744-2280
Purpose/Significance of Application: One of the early full-scale applications of SVE; used at a site with a complex hydrogeology.	Type/Quantity of Media Treated: Soil - 42,000 yds ³ - Sands, silts, and clays; air permeability 0.12 69,000 to 810,000 gpd/ft	-0.83 cm/sec; transmissivity -

Regulatory Requirements/Cleanup Goals:

Operation of SVE system until total chemical removal rate was less than 10 lbs/day and the chemical removal rate from individual wells decreased to 10% or less of the initial removal rate or until the chemical removal rate declined at a rate of less than 1% per day for 10 consecutive days

Results:

- Achieved the cleanup goal for the 10 lbs/day total chemical removal rate in 8 months
- After 16 months of operation, the removal rate for total chemicals was less than 4 lbs/day

Cost Factors:

- Actual capital costs \$2,100,000 (including installation of wells and vapor extraction system, and engineering services)
- Total operation and maintenance costs for 16 months \$1,800,000 (including water quality sampling and analysis, water level monitoring, equipment maintenance, engineering services, and carbon regeneration)

Soil Vapor Extraction at the Fairchild Semiconductor Corporation Superfund Site San Jose, California (Continued)

Description:

The Fairchild Semiconductor Corporation Superfund site (Fairchild) is a former semiconductor manufacturing facility which operated from 1977 to 1983. In late 1981, an underground storage tank used to store organic solvent was determined to be leaking. An estimated 60,000 gallons of solvents were released to the soil and groundwater. The primary contaminants of concern in the soil were 1,1,1-trichloroethane (TCA), 1,1-dichloroethene (DCE), tetrachloroethene (PCE), xylene, acetone, Freon-113, and isopropyl alcohol (IPA). Reported concentrations of total solvents in the soil were as high as 4,500 mg/kg, with maximum concentrations of TCA and xylenes in soil of 3,530 mg/kg and 941 mg/kg, respectively. As part of a multi-site cooperative agreement between EPA, the State of California, and Fairchild, Fairchild conducted site remediation activities at the San Jose site, including installing a soil vapor extraction (SVE) system. The California Regional Water Quality Control Board established a soil cleanup goal for this remediation of a total chemical rate of less than 10 lbs/day, along with specific performance goals for individual wells.

The SVE system, which consisted of 39 extraction wells, operated from January 1989 to April 1990. The most rapid reductions in contaminant concentrations occurred during the first 2 months of operation. After 8 months of operation, the SVE system achieved the cleanup goal of less than 10 lbs/day for total chemical removed. After 16 months of operation, the system achieved a chemical removal rate of less than 4 lbs/day, at which time the system was shut off.

The total costs for the SVE treatment system at Fairchild were approximately \$3,900,000. The actual costs were about 7% less than the projected costs because the time required for the cleanup was less than originally estimated. This treatment application was part of a multi-faceted cleanup program which included the installation of a slurry wall and dewatering of the aquifer which accelerated contaminant removal from the soil.

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Soil Vapor Extraction at the Hastings Groundwater Contamination Superfund Site Well Number 3 Subsite, Hastings, Nebraska

Site Name: Hastings Groundwater Contamination Superfund Site, Well Number 3 Subsite Location: Hastings, Nebraska	Contaminants: Chlorinated Aliphatics - Carbon tetrachloride, chloroform, trichloroethylene (TCE), 1,1-dichloroethane (DCA), 1,1,1-trichloroethane (TCA), and perchloroethylene (PCA) - Highest carbon tetrachloride	Period of Operation: June 1992 to July 1993 Cleanup Type: Full-scale cleanup
	concentration measured in soil gas was 1,234 ppmv at 112 ft below ground surface	
Vendor: Steve Roe Morrison-Knudsen Corporation 7100 East Belleview Avenue Suite 300 Englewood, CO 80111 (303) 793-5089	Technology: Soil Vapor Extraction - 10 extraction wells (5 deep, 3 intermediate, 2 shallow) - 5 monitoring well probes - An air/water separator, vacuum pump, and vapor phase granular activated carbon unit	Cleanup Authority: CERCLA - ROD Date: 9/26/89 - Fund Lead
SIC Code: 0723A (Crop Preparation Services for Market, Except Cotton Ginning- Grain Fumigation)		Point of Contact: Diane Easley (RPM) U.S. EPA Region 7 726 Minnesota Avenue Kansas City, KS 66101 (913) 551-7797
Waste Source: Spill; Other: Contaminated Aquifer	Type/Quantity of Media Treated: Soil - 185,000 yd ³ - Shallow zone: moisture content 26,3%, air permeability 1.9 x 10 ⁻¹⁰ cm ² .	
Purpose/Significance of Application: Full-scale SVE application at a Superfund site to treat a large quantity of soil contaminated with carbon tetrachloride.		
Regulatory Requirements/Cleanup Go Extraction rate for carbon tetrachlorid - Established in 1992 by EPA and Neb		

Soil Vapor Extraction at the Hastings Groundwater Contamination Superfund Site Well Number 3 Subsite, Hastings, Nebraska (Continued)

Results:

- The SVE system achieved the cleanup goal of 0.001 lb/hr extraction rate for carbon tetrachloride within 9 months of operation
- Approximately 600 pounds of carbon tetrachloride extracted, about 45 pounds extracted within the first 2 months of operation

Cost Factors:

- Total cost of \$369,628 (including project monitoring and control, procurement support, construction management (drilling, construction, system dismantlement, and grouting of wells), operations, maintenance, and reporting)

Description:

Soil Vapor Extraction (SVE) was used at the Hastings Groundwater Contamination Superfund site to treat approximately 185,000 cubic yards of soil contaminated with carbon tetrachloride (CCI). The site had become contaminated through accidental spills of carbon tetrachloride which was used in the 1960s and 1970s as a fumigant at a grain storage facility. Concentrations of CCI4 were measured in soil gas at the site at levels as high as 1,234 ppmv. A Record of Decision (ROD) was signed in September 1989, specifying SVE as an interim source control measure.

A pilot-scale treatability study (2 deep and 2 shallow extraction wells), conducted from April to May 1991, removed 45 pounds of CCl₄. The full-scale SVE system, based on the pilot-scale study, consisted of 10 extraction wells (5 deep, 3 intermediate, and 2 shallow) and was operated from June 1992 to July 1993. EPA and the Nebraska Department of Environmental Quality established an extraction rate for CCl₄ of 0.001 lb/hr as the cleanup goal with operation of the system required until field analytical results were verified through laboratory analysis and confirmation of no rebounding of CCl₄. The SVE system achieved the 0.001 lb/hr CCl₄ extraction rate within 6 months (January 1993) with the results verified and no rebounding confirmed by July 1993.

The total cost for this treatment application was approximately \$370,000. Actual costs were 17% less than projected. Cost savings were attributed to the effectiveness of the SVE system (the cleanup required only 9 months rather than the estimated 2 years based on treatability study results), and use of local contractors.

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah

Site Name: Hill Air Force Base, Site 914	Contaminants: Total Petroleum Hydrocarbons (TPH) - TPH concentrations in untreated soil	Period of Operation: October 1988 to December 1990
Location: Ogden, Utah	ranged from <20 to 10,200 mg/kg with average soil TPH concentration of 411 mg/kg	Cleanup Type: Full-scale cleanup
Vendor: Not Available	Technology: Soil Vapor Extraction followed by Bioventing SVE - 7 vent wells (Numbers 5-11 located in areas of highest contamination), 31 monitoring wells, 3 neutron access probes (for soil moisture monitoring) - Vent wells approximately 50 feet deep with 4-inch diameter PVC casings, screened	Cleanup Authority: State: Utah
SIC Code: 9711 (National Security)	from 10 to 50 feet below ground surface - Plastic liner installed over part of spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface - Monitoring wells - ranged in depth from 6 to 55 feet with 1-inch diameter PVC casing and a 2-foot screened interval to the bottom of the well - Catalytic incinerator for extracted vapor	Point of Contact: Robert Elliot OO-ACC/EMR 7274 Wardleigh Road Hill AFB, UT 84055
Waste Source: Spill of JP-4 Jet Fuel	- Air flow - 1,500 acfm (maximum), 700 acfm (typical) Bioventing - 4 vent wells (Numbers 12-15) located on the southern perimeter of the spill area; 31 monitoring wells; 3 neutron access probes (soil moisture monitoring) - Vent wells approximately 50 feet deep with 4-inch diameter PVC casings, screened from 10 to 50 feet below ground surface	
Purpose/Significance of Application: One of the early applications involving sequential use of SVE and bioventing technology.	 Monitoring wells - range in depth from 6 to 55 feet with 1-inch diameter PVC casings, screened from 10 to 50 feet below ground surface No treatment of extracted vapors required (hydrocarbon concentrations <50 mg/L; use of catalytic incinerator not required) Air flow - 250 acfm Soil moisture - 6 to 12% Nutrients added - C:N:P ratio of 100:10:10 	

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah (Continued)

Type/Quantity of Media Treated:

Soil

- 5,000 yds³ contaminated by spill (surface area of 13,500 ft²)
- Approximate extent of 10,000 mg/kg JP-4 contour covered area 100 by 150 feet
- Formation consists of mixed sands and gravels with occasional clay lenses
- Air permeability ranged from 4.7 to 7.8 darcies

Regulatory Requirements/Cleanup Goals:

- 38.1 mg/kg TPH
- Cleanup conducted under Utah Department of Health's "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites"

Results

- Achieved specified TPH levels
- Average TPH soil concentrations in treated soil reduced to less than 6 mg/kg
- 211,000 lbs of TPH removed in approximately 2 years of operation
- Removal rate ranged from 20 to 400 lbs/day

Cost Factors:

- Total costs of \$599,000, including capital and 2 years of operating costs
- Capital costs \$335,000 (including construction of piping and wells, other equipment, and startup costs)
- Annual operating costs \$132,000 (including electricity, fuel, labor, laboratory charges, and lease of equipment for 2 year operation)

Description:

In January 1985, an estimated 27,000 gallons of JP-4 jet fuel were spilled at the Hill Air Force Base Site 914 when an automatic overflow device failed. Concentrations of total petroleum hydrocarbons (TPH) in the soil ranged from <20 mg/kg to over 10,000 mg/kg, with an average concentration of about 400 mg/kg. The spill area covered approximately 13,500 ft².

The remediation of this spill area was conducted from October 1988 to December 1990 in two phases: the soil vapor extraction (SVE) phase followed by the bioventing phase. The SVE system included 7 vent wells (Numbers 5-11) located in the areas of highest contamination, 31 monitoring wells, and a catalytic incinerator. The typical air flow rate through the vent wells was 700 acfm, with a maximum of 1,500 acfm. In addition, a plastic liner was installed over part of the spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface. Within a year, the SVE system removed hydrocarbons from the soil to levels ranging from 33 to 101 mg/kg. Further reduction of the hydrocarbon concentration in the soil, to levels below the specified TPH limit, was achieved by using bioventing for 15 months. The bioventing system included 4 vent wells (Numbers 12-15), located on the southern perimeter of the spill area, and the monitoring wells used for SVE system. Because hydrocarbon concentrations were <50 mg/L in the extracted vapors, the catalytic incinerator was not required for this phase. Biodegradation was enhanced by injecting oxygen, moisture, and nutrients to the soil. Average TPH concentrations in the treated soil were less than 6 mg/kg.

The total capital cost for this application was \$335,000 and the total annual operating costs were \$132,000. In monitoring biodegradation rates, oxygen depletion was found to be a more accurate estimator of biodegradation rate than carbon dioxide formation. Carbon dioxide sinks, such as biomass, solubility in water, and reaction with the soil, limited the usefulness of carbon dioxide formation as a process control parameter.

Soil Vapor Extraction at North Fire Training Area (NFTA) Luke AFB, Arizona

Site Name: Luke Air Force Base, North Fire Training Area	Contaminants: Total Petroleum Hydrocarbons (TPH) Benzene, Toluene, Ethylbenzene, Xylenes (BTEX), and Methyl ethyl ketone (MEK) - Initial soil contamination in two fire	Period of Operation: October 1991 to December 1992
Location: Arizona	training pits - Benzene - 0.2 to 16 mg/kg; Toluene - 10 to 183 mg/kg; Ethylbenzene - 21 to 84 mg/kg; Xylenes - 69 to 336 mg/kg; and Total Recoverable Petroleum Hydrocarbons (TRPH) - 151 to 1,380 mg/kg	Cleanup Type: Full-scale cleanup
Vendor: Dan McCaffery Envirocon, Inc. James Ramm Rust Environment	Technology: Soil Vapor Extraction - 1 extraction well for each of 2 fire pits - Wells constructed with 35-foot screens to depths up to 57 feet	Cleanup Authority: State: Arizona
SIC Code: 9711 (National Security)	- Thermal oxidizer used for destruction of organics in extracted vapors	Point of Contact: Jerome Stolinksi CERMO U.S. Army Corps of Engineers, Omaha District
Waste Source: Fire Training Area	Type/Quantity of Media Treated: Soil - Permeable silty sands, very permeable, clean well graded to poorly graded sands, and permeable to low permeability inorganic silts - Moisture content 10% - Permeability of top soils ranged from 1 x 10 ⁻⁴ to 3 x 10 ⁻³ cm/sec - Porosity ranged from 36 to 46%	
Purpose/Significance of Application: Full-scale cleanup of two fire training pits using soil vapor extraction.		

Regulatory Requirements/Cleanup Goals:

- Arizona Action Levels for soil TPH 100 mg/kg; and BTEX 412 mg/kg
- Applicable state air emissions standards

Results

- Treated soil concentrations indicated TPH and BTEX were below the Arizona Action Levels
- 12,000 lbs of contaminants were removed during 30 weeks of operation
- Removal rate remained at 40 lbs/day after 30 weeks of operation
- Soil gas concentration reductions achieved in 6 months for 8 constituents ranged from 72 to 96% (benzene)

Soil Vapor Extraction at North Fire Training Area (NFTA) Luke AFB, Arizona (Continued)

Cost Factors:

Total cost - \$507.185

- Capital costs \$297,017 (including site preparation, site work, startup, engineering, pipes, buildings, permitting, and regulatory)
- Annual operating costs \$210,168 (including labor, laboratory charges, monitoring, fuel, electricity, maintenance, and disposal of residuals)

Description:

Routine fire training exercises were conducted at Luke Air Force Base in Arizona between 1963 and 1990, using petroleum, oil, and lubricant wastes, and JP-4 fuel. Fire training pits number 3 and 4 were used since 1973. During site investigations conducted between 1981 and 1989, soil at these two pits were determined to be contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). Cleanup goals were established for TPH and BTEX in soil based on Arizona Action Levels (AALs) - TPH at 100 mg/kg, and BTEX at 412 mg/kg.

A full-scale cleanup using Soil Vapor Extraction (SVE) of the soil in the two pits was conducted from October 1991 until December 1992. A thermal oxidizer was used for destruction of organic vapors extracted from the soil. The full-scale system, which used the thermal oxidizer, removed 12,000 pounds of contaminants in 30 weeks of operation. TPH and BTEX levels were below the AALs after five months of operation, with TPH and benzene reported as not detected in March 1992. Results of sampling in November 1992 showed ethylbenzene, toluene, and xylenes as not detected. System downtime was about 1% during this period. After a temporary shutdown period, an attempt to restart the system caused a malfunction in the thermal oxidizer and the destruction of the burner. As of December 1992, future activities at the site were pending.

The total cost of this treatment application was \$507,185. It was noted that the site investigation underestimated the amount of contamination at the site. A pilot-scale study was conducted at Luke prior to implementing the full-scale system. The pilot-scale system used vapor-phase granular activated carbon to treat extracted soil gas. Due to unexpectedly high concentrations of volatile organic constituents, the carbon supply was exhausted after two days of operation and the study was aborted. In discussing remediation of sites contaminated with JP-4 jet fuel, the report includes a discussion of the relative benefits of using SVE and bioventing techniques.

In Situ Soil Vapor Extraction at McClellan Air Force Base California

Site Name: McClellan Air Force Base Superfund Site, Operable Unit D, Site S	Contaminants: Chlorinated Aliphatics Tetrachloroethene (PCE), Trichloroethene (TCE), 1,1-Dichloroethene (1,1-DCE), Vinyl Chloride, 1,1,1-Trichloroethane (TCA), 1,2- Dichloroethene (1,2-DCA), Freon 113 - PCE, TCE, 1,1-DCE, TCA, and Freon 113 account for over 99% of the speciated VOC mass in the vadose zone - Maximum borehole concentration of VOCs in vadose zone reported up to 2,975,000 µg/kg	Period of Operation: Status - Ongoing Report covers - 1993 to 5/94
Location: Sacramento, California		Cleanup Type: Field Demonstration
Vendor: CH2M Hill	Technology: Soil Vapor Extraction - 17 vapor extraction wells in three contamination zones - 5 vacuum blowers, 2 vapor/liquid	Cleanup Authority: CERCLA and State: California - ROD Date: pending (scheduled for issuance mid-1995)
SIC Code: 9711 (National Security)	separators - Catalytic oxidizer and scrubber used to control air emissions - Total system average air flow rate was 2,500 scfm	Point of Contact: Kendall Tanner Remedial Project Manager McClellan, AFB
Waste Source: Disposal Pit (for fuel and solvents)	Type/Quantity of Media Treated: Soil Three zones of contamination - waste pit (landfilled silty sands and sandy silt with oily material, wire wood, debris, etc.); intermediate alluvium; and deep alluvium Permeability ranged from 0.001 (for silty clay) to 1.7 (for sand) darcies	
Purpose/Significance of Application: A demonstration of soil vapor extraction to remediate VOCs in waste pit materials and vadose zone soils, and to assess performance of catalytic oxidation and scrubbing.		

- Regulatory Requirements/Cleanup Goals:
 Cleanup criteria not yet established for this site at McClellan
 Air Emissions 95% destruction of total VOCs, required by the Sacramento Air Quality Management District

In Situ Soil Vapor Extraction at McClellan Air Force Base California (Continued)

Results:

- Demonstration not complete at time of report; no soil samples to characterize post-treatment vadose zone were collected at time of report
- Approximately 46,000 lbs of speciated VOCs were extracted and treated during initial 6 weeks of operation; 113,000 lbs during initial 15 weeks of operation
- TCE, 1,1-DCE, and TCA accounted for more than 90% of the mass of contaminants removed
- Up to 150,000 lbs of contaminants (hexane-equivalents) believed to have been biodegraded in situ during initial 6 weeks of operation
- Overall DRE averaged 99% for total VOCs during second and third months of demonstration; lower DRE in first month attributed to operational concerns

Cost Factors:

Field demonstration budget - \$1.8 million for 1993 and \$2.0 million for 1994 (including site characterization; air permeability testing; installation and operation of SVE wells; vapor probes and manifold; air/water separators; blowers; scrubber; catalytic oxidizer (rented); resin adsorption (rented); electronic beam technology testing; laboratory analysis; and engineering support)

Description:

The McClellan Air Force Base in Sacramento, California is an Air Force Command Logistics Center that has been in operation since 1943. The base was placed on the National Priorities List in 1987 and Site S within Operable Unit D is one of the areas of confirmed contamination at the base. Site S is the location of a former fuel and solvent disposal pit, used from the early 1940s to mid-1970s. Soil at Site S has been contaminated with chlorinated and petroleum-based volatile organic constituents (VOCs). No cleanup goals had been established for Site S at the time of this report. The report indicates that a Record of Decision for Operable Unit D (which includes the disposal pit site) is scheduled to be issued in mid-1995. A 95% destruction and removal efficiency (DRE) for total VOCs in the extracted vapors was required by the Sacramento Air Quality Management District.

A field demonstration of soil vapor extraction (SVE) at Site S began in mid-1993. This demonstration is being conducted as part of a series of field programs designed to optimize remedial technologies to be used in a full-scale cleanup at McClellan. This SVE system includes 17 vapor extraction wells, vapor/liquid separators, a catalytic oxidizer, and a scrubber. Results from the field demonstration of SVE to date showed that approximately 113,000 pounds of VOCs were extracted in 15 weeks of operation; mostly consisting of TCE, 1,1-DCE, and TCA. In addition, up to 150,000 pounds of contaminants (hexane-equivalents) were believed to have been biodegraded in situ during the initial 6 weeks of the SVE demonstration. The average DRE for total VOCs during the second and third months of the demonstration was 99 percent.

It was noted during this application that the heterogeneity of the soils at this site caused the radius of influence for the extraction wells to vary from 15 to 60 feet for a single well. The calculated mass of contaminants was almost two orders of magnitude less than the mass extracted in the first six weeks of system operation. It was also noted that SVE air pollution control systems should be designed with sufficient capacity to provide for operational flexibility.

Soil Vapor Extraction at the Rocky Mountain Arsenal Superfund Site Motor Pool Area (OU-18) Commerce City, Colorado

Site Name: Rocky Mountain Arsenal Superfund Site (Motor Pool Area - Operable Unit 18) Location: Commerce City, Colorado	Contaminants: Chlorinated Aliphatics - Trichloroethylene (TCE) - Levels of TCE in soil vapor of up to 65 ppm	Period of Operation: July 1991 to December 1991 Cleanup Type: Full-scale cleanup
Vendor: Rick Beyak Woodward-Clyde Federal Services 4582 S. Ulster St., Suite 1200 Denver, CO 80237 (303) 740-2600	Technology: Soil Vapor Extraction - 1 shallow vapor extraction well and 1 deep vapor extraction well - Shallow well screened between 13 and 28 feet below ground surface (bgs); deep well	Cleanup Authority: CERCLA - Federal Facilities Agreement - ROD Date: 2/26/90
SIC Code: 7699 (Repair Shops and Related Services, Not Elsewhere Classified)	screened between 43 and 58 feet bgs Liquid/vapor separator tank, sediment filter, and regenerative blower Exhaust air from blower treated using two granular activated carbon systems in series	Point of Contact: James D. Smith Program Manager Rocky Mountain Arsenal Attn: AMCPM-RME Commerce City, CO 80022- 1749 (303) 289-0249
Waste Source: Other: Motor Vehicle, Railcar, and Heavy Equipment Maintenance, Repair, and Cleaning Activities Purpose/Significance of Application: This application demonstrated that a pilot-scale SVE system removed sufficient vapor contaminants from the vadose zone, and expansion of the system beyond a pilot-scale was not necessary.	Type/Quantity of Media Treated: Soil - 34,000 yd³ (70 ft radius by 60 ft deep) - Unconsolidated deposits beneath Motor Pool Area consist of discontinuous sand and gravel lenses - 1-3 foot low-permeability clayey sand to clay layer 32 to 38 feet bgs - Moisture content - 4.7 to 30.9%; permeability - 167 darcys at 38 ft bgs and 2,860 darcys at 55 ft bgs	

Regulatory Requirements/Cleanup Goals:

- No specific cleanup goals were specified for Motor Pool Area OU-18

Results:

- TCE concentrations decreased to less than I ppm after 5 months of operation of the SVE system
- Rate of TCE extraction decreased from 35 pounds per month to less than 10 pounds per month
- Approximately 70 pounds of TCE removed during operation of the system

Soil Vapor Extraction at the Rocky Mountain Arsenal Superfund Site Motor Pool Area (OU-18) Commerce City, Colorado (Continued)

Cost Factors:

- Costs attributed to treatment activities: \$75,600 (installation and operation)
- Costs attributed to before-treatment activities: \$88,490 (including mobilization and preparatory work, monitoring, and laboratory analytical)
- Costs attributed to after-treatment activities: \$19,650 (including pilot study)

Description:

Soil vapor extraction (SVE) was performed at the Rocky Mountain Arsenal (RMA) Superfund site, Motor Pool Area, in Commerce City, Colorado to remove halogenated volatile organic compounds (VOCs), primarily trichloroethylene, from the vadose zone. The Motor Pool Area at RMA, referred to as Operable Unit 18, had been used for cleaning and servicing equipment, vehicles, and railroad cars, and for storing diesel, gasoline, and oil products in aboveground and underground storage tanks. VOCs, detected in the Motor Pool Area's soil and groundwater have been attributed to releases of chlorinated solvents used during cleaning operations; these solvents were discharged through floor drains and pipes into unlined ditches at the site.

This system was initially considered to be a pilot study because it was expected to provide performance data on SVE at this site that could be used to expand the system to a full-scale operation. This application, operated from July to December 1991, demonstrated that a pilot-scale SVE system removed sufficient vapor contaminants from the vadose zone, and expansion of the system beyond pilot-scale was not necessary. The SVE system used within the Motor Pool Area consisted of one shallow vapor extraction well and one deep vapor extraction well. Four clusters of vapor monitoring wells were installed to aid in the assessment of the performance of the SVE system. TCE levels in soil vapors collected from the vapor monitoring wells were reduced to non-detect or to levels of less than 1 ppm from initial vapor monitoring well samples as high as 65 ppm. Approximately 70 pounds of TCE were recovered during this cleanup action.

The operating parameters collected during the system's 1991 operation indicated that a clay lense located beneath the site affected the SVE system's performance by limiting both the shallow and deep vapor extraction wells' vertical zones of influence. The contract award cost for procuring, installing, and operating the SVE pilot system, as well as preparing a pilot study report was \$182,800. This cost was approximately 15% less than the preliminary cost estimate provided by the remediation contractor for the project. Factors contributing to the lower cost included lower construction and system operating costs.

Soil Vapor Extraction at the Sacramento Army Depot Superfund Site, Tank 2 Operable Unit Sacramento, California

Site Name: Sacramento Army Depot Superfund Site, Tank 2 (Operable Unit #3)	Contaminants: Chlorinated and Non-Chlorinated Aliphatics - 2-Butanone (0.011 to 150 mg/kg);	Period of Operation: August 1992 to January 1993
Location: Sacramento, California	Ethylbenzene (0.006 to 2,100 mg/kg), Tetrachloroethene (0.006 to 390 mg/kg), and Xylenes (0.005 to 11,000 mg/kg)	Cleanup Type: Full-scale cleanup
Vendor: James Perkins Terra Vac, Inc. 14798 Wicks Boulevard San Leandro, CA 94577 (510) 351-8900	Technology: Soil Vapor Extraction - 8 vacuum extraction wells, positive displacement blower, vapor-liquid separator, and primary and secondary carbon filters	Cleanup Authority: CERCLA and Other: Federal Facilities Agreement - ROD Date: 12/9/91
SIC Code: 3471 (Electroplating, Plating, Polishing, Anodizing, and Coloring) 3479 (Coating, Engraving, and Allied Services, Not Elsewhere Classified)	- Wells installed to depths of 15 to 28 feet below ground surface	Point of Contact: Dan Obern Sacramento Army Depot 8350 Fruitridge Road Sacramento, CA 95813-5052 (916) 388-2489
Waste Source: Underground Storage Tank	Type/Quantity of Media Treated: Soil - 650 yd³ (25 ft by 35 ft by 20 ft deep) - Silt with clay content of <30%; moisture content - 25.6 to 26.5%; air permeability 1.7 x 10⁻¹ to 6.2 x 10⁻⁵ cm/sec; porosity - 44.3 to 45.8%; TOC 0.011 to 0.44%	
Purpose/Significance of Application: This application of SVE was in a relatively small volume of low permeability, heterogenous, contaminated soil.		

Regulatory Requirements/Cleanup Goals:

- 1991 ROD specified soil cleanup levels for the Tank 2 Operable Unit of 2-Butanone (1.2 ppm); ethylbenzene (6 ppm); tetrachloroethene (0.2 ppm); and total xylenes (23 ppm)
- Cleanup levels were to be achieved within 6 months of system operation

Results:

- The specified cleanup levels were achieved within six months of system operation
- Levels of 2-butanone, ethylbenzene, tetrachloroethene, and total xylenes were reduced to below detection limits

Cost Factors:

Total cost of \$556,000 - costs directly associated with treatment (including mobilization/setup, startup, operation, sampling and analysis, demobilization)

- \$290,000 of total cost attributed to treatment of non-Freon contaminants (adjusted assuming operation costs equivalent for Freon and non-Freon contaminants)

Soil Vapor Extraction at the Sacramento Army Depot Superfund Site, Tank 2 Operable Unit Sacramento, California (Continued)

Description:

The Sacramento Army Depot (SAAD) located in Sacramento, California is an Army support facility. Past and present operations conducted at the site include equipment maintenance and repair, metal plating, parts manufacturing, and painting. During investigations of the facility in 1981, soil contamination was identified in the area of an underground storage tank and designated as Tank 2 Operable Unit. Tank 2 had been used to store solvents and the primary contaminants of concern included ethylbenzene, 2-butanone, tetrachloroethene, and xylenes. These constituents were detected in the soil at levels up to 11,000 mg/kg. A Record of Decision (ROD), signed in December 1991, specified soil cleanup levels for the four primary constituents of concern and specified a six month timeframe for achieving these levels. SVE was selected for remediating the contaminated soil because it was determined to be the most cost effective alternative.

The SVE system consisted of 8 vacuum extraction wells, a vapor-liquid separator, and primary and secondary carbon adsorption units, and was operated from August 6, 1992 to January 25, 1993. The system achieved the specified soil cleanup levels a month ahead of the specified timeframe. In addition, the SVE system removed approximately 2,300 pounds of VOCs. During system operation, Freon 113 was unexpectedly encountered. Extraction of Freon 113 significantly increased the quantity of carbon required to treat the extracted vapors.

The total treatment cost for this application was \$556,000. This cost was greater than originally estimated primarily as a result of the additional carbon required as a result of the presence of Freon 113. A computer model treatability study was used for this application. The study predicted SVE using 4 extraction wells could reduce concentrations of volatile organics to non-detectable levels within 6 months.

Soil Vapor Extraction at the SMS Instruments Superfund Site Deer Park, New York

Vendor: Bill Ballance Four Seasons Environmental, Inc. 3107 South Elm - Eugene Street P.O. Box 16590 Greensboro, NC 27416-0590 (919) 273-2718 Tech Soil V - T - T - T - E - II - T - II - T - II - II - II - II -	rea soils nology: Vapor Extraction wo horizontal vapor extraction wells nstalled in trenches 15-feet deep, 2-feet vide, and 75-feet long Extracted vapors treated using catalytic ncineration and scrubbing	Cleanup Authority: CERCLA and State: New York - ROD Date: 9/29/89 - Fund Lead
616 6 1	Remote monitoring used for process	Point of Contact: Abram Miko Fayon Remedial Project Manager U.S. EPA Region 2 Jacob K. Javits Federal Building New York, NY 10278-0012
Underground Storage Tank; Other: Soil Leaching Pool - 1.	Type/Quantity of Media Treated: Soil - 1,250 cubic yards of soil treated in this application - Well-sorted sands to silty sands with fine gravel - Permeability 0.00227 to 0.00333 cm/sec	

- Additional criteria specified for soil cleanup effort based on percent reductions
- Air emissions required to meet New York State ambient air guidelines for toxic air contaminants

Results:

- Soil cleanup levels and criteria were achieved within approximately 400 days after system operation began

Remediation Case Studies: Soil Vapor Extraction

Soil Vapor Extraction at the SMS Instruments Superfund Site Deer Park, New York (Continued)

Cost Factors:

- Total treatment system cost was \$450,520 (including \$182,700 for one year of monthly operation and maintenance, mobilization, system design and construction, demobilization, drum relocation)

Description:

The SMS Instruments site in Deer Park, NY was used for overhauling military aircraft components. Past waste disposal practices at the site included discharging untreated wastewater from degreasing and other refurbishing operations to an underground leaching pool. In addition, jet fuel was stored at the site in an underground storage tank. The results of a Remedial Investigation at the site indicated soil contamination in the areas of the leaching pool and the underground storage tank. Contaminant concentrations in soil ranged as high as 1,200 mg/kg for volatiles and 1,800 mg/kg for semivolatiles. The New York Department of Environmental Conservation developed soil cleanup levels for 9 volatile and 9 semivolatile constituents.

Soil vapor extraction (SVE) was used at SMS to treat the contaminated soil. The SVE system, operated from May 1992 to October 1993, included two horizontal vapor extraction wells installed in trenches adjacent to the contaminated areas, a catalytic oxidizer, and acid gas scrubber. Based on the results of soil boring data, collected in June 1993, SVE achieved the cleanup levels and standards for 17 of the 18 specified organic constituents. For one constituent, BEHP, concentrations were above the specified cleanup level. However, according to the EPA RPM, this result may be an anomaly since the concentration of BEHP in the treated soil was greater than concentrations of BEHP identified during the remedial investigation at the site. In addition, the state ambient air guidelines were met during the operation of this system.

The total treatment cost for this application was \$450,420. The treatment vendor indicated that the costs associated with instrumentation were greater than anticipated and that there was a problem with corrosion of ductwork. The vendor suggested several ideas for reducing costs of future similar applications including ways to reduce air monitoring costs.

Remediation Case Studies: Soil Vapor Extraction

Soil Vapor Extraction at the Verona Well Field Superfund Site, Thomas Solvent Raymond Road (OU-1) Battle Creek, Michigan

Site Name: Verona Well Field Superfund Site, Thomas Solvent Raymond Road (OU-1) Location: Battle Creek, Michigan	Contaminants: Chlorinated and Non-Chlorinated Aliphatics Tetrachloroethene (PCE), 1,1,1- trichloroethane, acetone, and toluene Light nonaqueous phase liquids (LNAPL) in groundwater Volume of organic compounds estimated to be 3,900 lbs in groundwater and 1,700 lbs in soil	Period of Operation: March 1988 to May 1992 Cleanup Type: Full-scale cleanup				
Vendor: Robert Pinewski Terra-Vac, Inc. 9030 Secor Road Temperance, MI 48182 (313) 847-4444	Technology: Soil Vapor Extraction - 23 extraction wells with 14 of 23 wells in operation at a given time - Catalytic oxidation and activated carbon adsorption of offgases	Cleanup Authority: CERCLA - ROD Date: 8/12/85 - Fund Lead				
SIC Code: 7389 (Business Services, Not Elsewhere Classified)		Point of Contact: Margaret Guerriero (RPM) U.S. EPA Region 5 77 W. Jackson Boulevard Chicago, IL 60604 (312) 886-0399				
Waste Source: Other: Solvent Storage, Blending, Repackaging, Distribution, and Disposal	Type/Quantity of Media Treated: Soil - 26,700 yd³ of soil (based on capture zone of content < 5%					
Purpose/Significance of Application: EPA's first application of SVE at a Superfund site.	- Moisture content 5%					

Regulatory Requirements/Cleanup Goals:

- 1991 ROD specified soil and groundwater cleanup standards for 19 constituents
- Standards in soil ranged from 0.014 mg/kg for carbon tetrachloride, 1,1-dichloroethane, 1,1-dichloroethene, and tetrachloroethene to 16 mg/kg for toluene
- Standards in groundwater ranged from 0.001 mg/L for vinyl chloride, 1,1,2-trichloroethane, tetrachloroethene, and benzene to 0.8 mg/kg for toluene

Results:

- SVE achieved the cleanup standards for all VOCs
- A total of 45,000 lbs of VOCs were removed

Remediation Case Studies: Soil Vapor Extraction

Soil Vapor Extraction at the Verona Well Field Superfund Site, Thomas Solvent Raymond Road (OU-1) Battle Creek, Michigan (Continued)

Cost Factors:

- Cost attributed to treatment activities approximately \$1,600,000 (including solids preparation and handling, mobilization/setup, startup/testing/permits, operation, cost of ownership, and demobilization)
- Cost attributed to before-treatment activities approximately \$480,000 (including monitoring, sampling, testing and analysis, and drums/tanks/structures/miscellaneous demolition and removal)
- Cost attributed to after-treatment activities approximately \$5,000 (including well abandonment and disposal of drums)

Description:

The Verona Well Field Superfund site is the location of the former primary well field that supplied potable water for the city of Battle Creek, Michigan. In early 1984, 27 of the 30 wells were determined to be contaminated. The Thomas Solvent Raymond Road area was determined to be a source of contamination. Soil in this area was determined to be contaminated with chlorinated solvents, primarily tetrachloroethene and 1,1,1-trichloroethane. The amount of volatile organic compounds in the soil at this site was estimated to be 1,700 pounds.

Full-scale operation of an SVE system to treat the soil began in March 1988 and ran intermittently until May 1992. Over the course of the SVE operation, both carbon adsorption and catalytic oxidation were utilized to treat the extracted vapors prior to atmospheric discharge. Dual vacuum extraction and nitrogen sparging were implemented to enhance recovery rates during the latter stages of the groundwater remediation effort. A total of 45,000 pounds of VOCs were removed from the subsurface soil, and 10,000 pounds from the groundwater, during the remediation. Cleanup verification sampling of the soil occurred in June 1992 and the analytical results indicated that SVE reduced the constituent concentrations in the soil at this operable unit. The constituent-specific soil cleanup standards established in a 1991 ROD were met.

The cost attributed to treatment activities for this SVE application was approximately \$1,600,000. The SVE system used at Verona accommodated both carbon adsorption and catalytic oxidation for the treatment of extracted vapors. Catalytic oxidation was identified as preferable for treatment of extracted vapors instead of carbon adsorption for the period of the application where the contaminant mass removed by SVE was much greater than 10 to 20 lb/day.

APPENDIX E

Compact Agreement & Stability Monitoring Flowchart (from IDEM RISC Technical Guidance)

2008-13811 ELKHART CHTY RECORDER CHRISTOPHER J ANDERSON FILED FOR RECORD AS PRESENTED (COPY)

RESIDENTIAL COMPACT AGREEMENT

1000 JUN -4 P 1:355

THIS AGREEMENT is made and entered into as of the day o
, 2008, by and between the CITY OF ELKHART, INDIANA, a political
subdivision of the State of Indiana, acting by and through its Board of Public Works
("Elkhart"), and Patricia A. Miller whose address is 53588 Kershner Ln., Elkhart
Indiana ("Utility Petitioner").

RECITALS:

- A. This Agreement is entered into pursuant to the authority stated at I.C. 36-4-3-21 and Elkhart City Ordinance No. 4393.
- B. Elkhart owns, operates and maintains a public water system within the corporate boundaries of the City of Elkhart and the unincorporated parts of the Elkhart County, Indiana, included within the Elkhart Utilities Urban Services Boundary.
- C. Utility Petitioner is the owner of certain residential real estate located outside of the territorial boundaries of the City of Elkhart, Indiana, and the Elkhart Utilities Urban Services Boundary, in Elkhart County, Indiana, which real estate is legally described in Exhibit "A" and depicted in Exhibit "B" of this Agreement ("Real Estate"). Utility Petitioner has been advised that, through no fault of its own, the groundwater under its Real Estate is or may become contaminated by certain organic solvents. Geocel Corporation has offered to extend water services to the Utility Petitioner, as well as other similarly situated homeowners (the "Project"); however, because the Real Estate is located outside the territorial boundaries of the City of Elkhart, Indiana, the Real Estate is not eligible to receive Elkhart public water services unless Utility Petitioner agrees to certain terms and conditions set forth in an Elkhart Compact Agreement.
- D. Geocel Corporation is willing to construct and extend, at its expense, the water facilities located in the public right-of-way near County Road 106 and Kirshner Lane in Elkhart County, Indiana, to a point adjacent to the Real Estate; and to connect the water facilities to Elkhart's public water systems and, upon completion, dedicate them to Elkhart ("Utility Extensions").
- E. Subject to the terms and conditions set forth in this Agreement, Elkhart is willing to accept the Utility Extensions as part of its public water system upon completion of construction, appropriate inspections and acceptance by the City Engineer.
- F. Utility Petitioner acknowledges that, as consideration for authorizing and approving the Utility Extensions described herein, Utility Petitioner and its successors and assigns will not object to or remonstrate against a petition to annex the Real Estate into the City of Elkhart after it becomes aware that the Real Estate meets the contiguity requirement of law, as stated at I.C. 36-4-3-1.5, as amended, entitling the Real Estate to be annexed into the City of Elkhart.

NOW, THEREFORE, in consideration of the forgoing, the mutual covenants and agreements contained herein, and other good and valuable consideration, the receipt and sufficiency of which are hereby acknowledged, the parties do hereby agree as follows:

1. <u>Utilities Service</u>. Subject to Utility Petitioner's and Utility Petitioner's successors' and assigns' satisfaction of their obligations under this Agreement and compliance with Elkhart's Municipal Code, and subject to Elkhart's acceptance of the Utility Extension, Elkhart will provide water service to the Real Estate in accordance with the Elkhart Municipal Code.

2. Connection Charges and User Fees.

- a. Geocel shall pay on behalf of the Utility Petitioner all applicable connection charges ("Water Assessment Amount") for connection to the Elkhart public water system, which amount shall be paid to Elkhart prior to the date the water main extension first becomes operational.
- b. Utility Petitioner and its successors and assigns shall pay regular monthly water user fees and delinquency penalties, if applicable, as described in Ordinance No. 4097, as amended or replaced, and Ordinance No. 2846, as amended or replaced. The fees and delinquency amounts may be collected by Elkhart through any lawful remedy, including, where applicable, the placing of and foreclosure of liens on any or all of the Real Estate as provided by law.

3. Ownership of Extension.

- a. The Utility Extension and all pipe and other materials used in construction of the Utility Extension located in, under, or below any public streets, highways, easements, or right-of-way, including any right-of-way granted to Elkhart over any private property, shall become the absolute property of Elkhart by passage of ownership thereto, upon final inspection and acceptance thereof, and Utility Petitioner or its successors shall then have no right, title, or interest therein thereafter.
- b. Upon the acceptance of the Utility Extension by Elkhart, the same shall become a part of the public water system of Elkhart, and appropriate easements for the operation, maintenance, repair and replacement of the Utility Extension shall be granted to Elkhart.
- 4. <u>Maintenance</u>. After acceptance of the Utility Extension, Elkhart shall thereafter maintain the Utility Extension as reasonably required.

5. Water Service Line.

a. Geocel shall, at its sole expense, install the water service line, and the installation of the water service line shall meet Elkhart's specifications. The cost and maintenance of the water service line from the point of tap-in (including the tap) to the water main line shall thereafter be at Utility Petitioner's sole expense.

- 6. <u>Term.</u> This Agreement shall terminate fifteen (15) years from the effective date of this Agreement, or when the Agreement is terminated or reduced in duration by written agreement of the parties, or upon annexation of any or all of the Real Estate, whichever event first occurs.
- 7. Remonstrance Waiver. Utility Petitioner and Utility Petitioner's successors and assigns, individually and collectively, shall not object to nor file a remonstrance against annexation of any or all of the Real Estate by the City of Elkhart, Indiana; shall not appeal from any order or judgment annexing any or all of the Real Estate to the City of Elkhart; and shall not file a complaint or action against any annexation proceedings that affect any or all of the Real Estate, and shall accordingly release and waive all rights to remonstrate against any pending or future annexation of any or all of the Real Estate by the City of Elkhart, Indiana.

8. Default.

- a. Should Utility Petitioner or its successors and assigns fail to comply with any of the terms of this Agreement, such failure to comply shall be deemed a default. Should Utility Petitioner or its successors and assigns fail to cure a default within ninety (90) days of its receipt of a written notice thereof from Elkhart, Elkhart shall have the right, in its sole discretion, upon a sixty (60) day certified mail written notice to Utility Petitioner or its successors and assigns to discontinue and/or withhold any or all future water services by:
 - (i) plugging and severing the connection between any pipe or facility of Utility Petitioner to the water main extension and/or any other facility of Elkhart that transports any water to the Real Estate; and/or
 - (ii) any other means.
- b. Should Elkhart not avail itself of any right or remedy in this Agreement, the same shall not constitute a waiver as to any future or prior default or breach by Utility Petitioner or Utility Petitioner's successors and assigns.
- 9. <u>Notices</u>. All notices and other communications hereunder shall be deemed given if same are in writing and are delivered personally, by ovemight carrier, by mail, or other verifiable means, to the following addresses:

If to Elkhart:

Elkhart City Board of Public Works

229 South Second Street Elkhart, Indiana 46516

With a copy to:

Elkhart City Corporation Counsel

229 South Second Street Elkhart, Indiana 46516

If to Utility Petitioner:

Patricia A. Miller 53588 Kershner Ln. Elkhart, Indiana 46514

If to any successor and assign of Utility Petitioner, then notice shall be provided to such person or entity at the address(es) provided to Elkhart.

- 10. <u>Assignment</u>. Utility Petitioner shall not assign this Agreement or any portion thereof without the prior written consent of Elkhart, which may be withheld in Elkhart's sole discretion.
- 11. <u>Indiana Law</u>. This Agreement will be construed in accordance with the laws of the State of Indiana.
- 12. Ordinance No. 4101. If, in the course of performance of this Agreement, Utility Petitioner violates certain City ordinances in the manner described at subsections 2(A)(1) through 2(A)(5) of Elkhart City Ordinance No. 4101, Elkhart may assert that such violation is a material breach of this Agreement. A copy of said Ordinance is available to Utility Petitioner upon request. However, such a violation shall not be a sufficient sole cause for Elkhart to terminate this Agreement.
 - 13. <u>Additional Responsibilities of Utility Petitioner and Its Successors and Assigns.</u>
- a. "Utility Petitioner's successors and assigns," as same appears in this Agreement, is defined as any and all of Utility Petitioner's assignees and any and all of Utility Petitioner's successor(s) in title to any or all of the Real Estate including, but not limited to, Utility Petitioner's applicable executors, administrators, devisees, transferees, and grantees.
- b. This Agreement shall run with the land and all the terms, covenants, and conditions of this Agreement shall be binding upon Utility Petitioner and Utility Petitioner's successors and assigns.
- c. Utility Petitioner and each of the Utility Petitioner's successors and assigns that owns any or all of the Real Estate in fee simple (sometimes referred to as "such real estate") after the execution date of this Agreement (sometimes referred to as "prior owner(s)") shall remain primarily liable for all obligations under this Agreement until Elkhart receives a copy of the duly recorded deed, establishing the transfer of title to such real estate in fee simple to a successor (the "Transfer Document"). Upon receipt by Elkhart of the Transfer Document, all provisions of this Agreement that apply to such real estate shall be the responsibility of the successor, and the prior owner(s) of such real estate shall have no further responsibility to satisfy such obligations accruing after the transfer date shown on the Transfer Document. However, the prior owner(s) of any remaining portion of the Real Estate shall continue to be responsible for all obligations under this Agreement that apply to any remaining portion of the Real Estate owned by the prior owner(s).

- d. Should any portion of the Real Estate be transferred to a successor in fee simple as described in Subsection 13 (c), all provisions of this Agreement shall be binding on the successor for that transferred portion of the Real Estate in the same manner as such provisions of this Agreement are initially binding on Utility Petitioner for the entire Real Estate. The fee simple owner(s) of any remaining portion of the Real Estate shall be bound by all provisions of this Agreement to the same extent that the Utility Petitioner is initially bound for the entire Real Estate.
- 14. <u>Deed Condition</u>. Utility Petitioner shall include in all written instruments conveying title to any portion or all of the Real Estate to a third party an express covenant stating that the third party is taking title to the Real Estate subject to the terms and conditions of this Agreement.
- 15. <u>Subsequent Acts</u>. The parties agree that they will, at any time and from time to time, from and after the execution of this Agreement, upon request, perform or cause to be performed such acts, and execute, acknowledge and deliver or cause to be executed, acknowledged, and delivered such documents as may be reasonably required for the performance by the parties of any of their obligations under this Agreement.
- 16. <u>Non-Waiver</u>. No delay or failure by either party to exercise any right hereunder and no partial or single exercise of any such right, shall constitute a waiver of that or any other right, unless otherwise expressly provided herein.
- 17. <u>Headings</u>. Headings in this Agreement are for convenience only and shall not be used to interpret or construe its provisions.
- 18. <u>Severability</u>. Wherever possible, each provision of this Agreement shall be interpreted in such manner as to be effective and valid under applicable law, but if any provision of this Agreement shall be prohibited by or invalid under applicable law, such provision shall be ineffective only to the extent of such prohibition or invalidity, without invalidating the remainder of such provision or the remaining provisions of this Agreement.
- 19. <u>Entire Agreement</u>. There are no representations, covenants, warranties, promises, agreements, conditions, or undertakings, oral or written, between Elkhart and Utility Petitioner other than herein set forth. Except as herein otherwise provided, no subsequent alteration, amendment, change, or addition to this Agreement shall be binding upon Elkhart or Utility Petitioner unless in writing and signed by them.

IM X See the attached addendum

IN WITNESS WHEREOF, Elkhart and Utility Petitioner have duly executed this Agreement on the day and year first above written.

UTILITY PETITIONER	CITY OF ELKHART, INDIANA, acting by and through its Board Of Public Works
Patricia A. Willer	Ami Lam
PATRICIA A. MILLER	Arvis Dawson, President
	Michael Machlan, Vice President
	andy lones
	Andrew Jones, Member
	Andrew Carter, Member
	Frances O'Hara, Member
I affirm, under the penalties for perjury, that I have taken reasonable care to redact each Social Security number in this document, unless required by law. Chirag Petal	ATTEST: Mull
	Nancy Gill, Secretary

This Instrument was prepared by Vlado Vranjes (Attorney No. 19229-53), Corporation Counsel, City of Elkhart, 229 S. Second Street, Elkhart, Indiana 46516. I affirm, under the penalties for perjury, that I have taken reasonable care to redact each Social Security number in this document, unless required by law. Vlado Vranjes

STATE OF INDIANA)) SS:	
COUNTY OF ELKHART)	
personally appeared	Notary Public in and for said County and State, he execution of the foregoing Agreement on the
in Witness Whereof, I have here seal.	eunto subscribed my name and affixed my official
My Commission Expires: September 19, 2009	Martha F. Milbourn, Notary Public Resident of St. Joseph County
STATE OF INDIANA)) SS: COUNTY OF ELKHART)	
personally appeared Arvis Dawson, Mand Frances O'Hara, in their capacity a City of Elkhart, Indiana, for and on beh	Notary Public in and for said County and State, Michael Machlan, Andrew Jones, Andrew Carter as members of the Board of Public Works for the laft of the City of Elkhart, Indiana, and being duly be execution of the foregoing Agreement on the _, 2008.
In Witness Whereof, I have here seal.	eunto subscribed my name and affixed my official
My Commission Expires:	, Notary Public Resident of County

EXHIBIT A

LEGAL DESCRIPTION

Parcel Identification Numbers are

20-02-26-328-005.000-026

Mar 24 2 28 PM 87 Parcel No.

87 006313

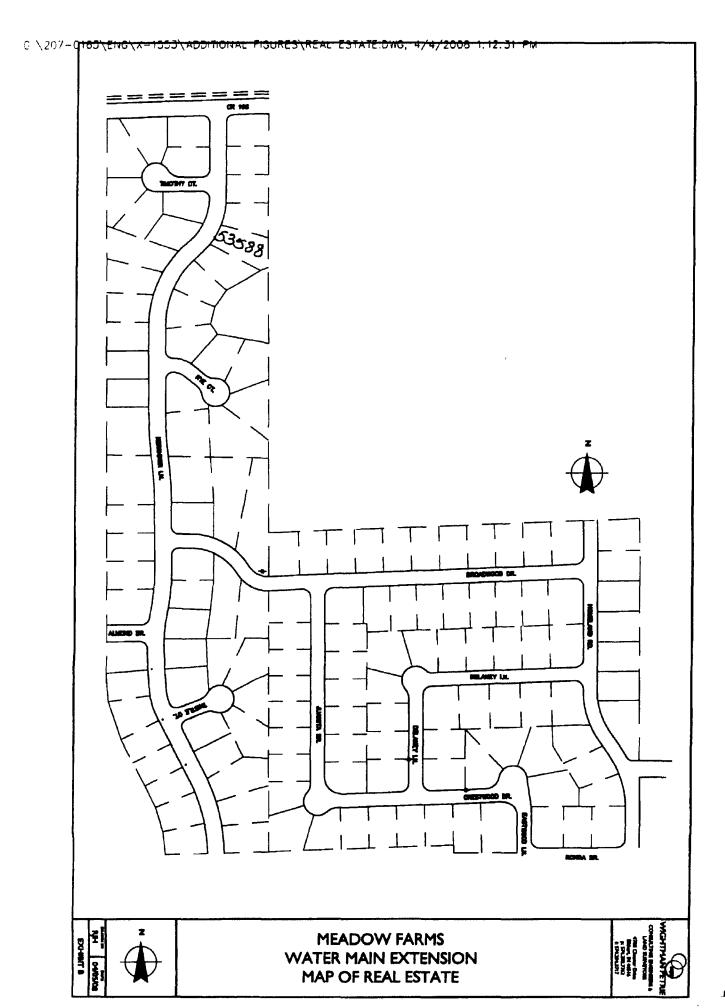
588 Kershner Lane

💪 THIS INDENTURE WITNES	REPTU TL.	ERNEST R. BEBRR	A KRISTING T.
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of Elkhart County			
		•	, CONVEY
AND WARRANT to	FAIRL	TH W. WITHOUT	
511			(Grantee
of Elkhart County,			
of Ten			
valuable consideration, the rece	-		
described real estate in	Elkhart	County, State of In	diana:
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Subject to unper restrictions ar		state taxes and appoint of record.	olicable
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Mar. 24	4.87		
	1877.		
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Subject to any and all easement of the season of the seaso	SS and for said C Kristine L of the foregod tions therein on Signature Printed Resident of	Rershner Lane, Elk Iress unless otherwise indi- ated this deed this	cated below. 8 day of (SEAL) ine L. Beber illy appeared tho, having been duly h. 19 87 Notary Public County, Indiana.

EXHIBIT B

MAP OF REAL ESTATE

ELDS01 RWP 219167v1



TEMPORARY EASEMENT AGREEMENT

THIS AGREEMENT is made	and entered	l into this	वाड	day of April	2008,	by and	between
Patricia A. Miller	, hereinafter	referred	to as	"Homeowner,	and	Geocel	Holdings
Corporation, hereinafter referre	ed to as "Geo	ocel."					
RECITALS							
The nartice recite and declare:	ı						

Homeowner is the owner of certain real property at the address

53588 Kershner Ln. Elkhart, IN 46514

- B. Geocel is providing a public potable water supply from the City of Elkhart to Homeowner's property, and abandoning and sealing the water supply well on Homeowner's property.
- C. Homeowner wants to receive potable water from the public water supply. Homeowner understands that this will involve having underground lines placed on his or her property, having a water meter installed within his or her building/house, having any existing water pump and well disconnected, and having his or her existing water supply well abandoned and sealed, in accordance with the requirements of the Indiana Department of Natural Resources.
- D. Geocel and/or their contractors are qualified and willing to perform the work discussed above.
- E. In consideration of the foregoing and the mutual covenants contained in this Agreement, Homeowner and Geocel agree to follow:
- 1. Grant of Easement. Homeowner grants to Geocel (including their contractors, subcontractors, agents, employees, successors and assigns) a temporary easement or right to use and occupy such portions of his or her real property temporarily as is necessary, during the construction of underground water lines, water service connection, water meter installation, plumbing revisions, and pump and well abandonment. Geocel's contractors are permitted to enter upon Homeowner's real property, make necessary excavations, lay water lines, seal the existing well, and abandon the existing water supply piping. In addition, Geocel's contractors are permitted to enter any building for the purpose of attaching meter lines to the public water supply,

installing a water meter, and relocating and modifying the potable water piping within the building. Geocel also has the right to store temporarily all necessary equipment, materials and excavated earth on the Homeowner's property.

- 2. **Underground Facilities**. Homeowner will provide Geocel with available information about the location of underground utilities, telephone cables, electric lines, gas lines, sprinkler systems and any other underground facility located on the property. Geocel will try to lay new underground pipelines at convenient locations and where the pipelines will not disturb surface improvements, pavements, planting and trees.
- 3. Facilities in Building/Houses. Homeowner will provide Geocel with available information about the location of potable water piping, pumps and related plumbing facilities within the building/house to be served. Homeowner will allow Geocel to expose all facilities and piping necessary in order to install potable water service and relocate or modify the potable water system within the building/house.

4. Condition of Property.

- a. Following the installation of the water lines, water meter, piping relocation or modification and well abandonment, Geocel will be responsible for removing from the property all debris, surplus material and construction equipment.
- b. Surplus excavated earth will be mounded over the trench or used for filling and leveling on the premises, or hauled away, at the Homeowner's option.
- c. Geocel will repair, reconstruct, or replace any sections of fences or walls removed for access and construction on Homeowner's real property. Geocel will attempt to match existing colors, conditions and materials to Homeowner's satisfaction.
- d. Geocel will patch/repair all pavement damages caused by their work on Homeowner's real property.
- 5. **Termination**. The easement granted by this Agreement for temporary construction use of portions of the property shall cease and terminate immediately following completion of construction, final inspection, inspection of the waterlines, and performance by Geocel of the conditions and covenants set out in this Agreement.

- 6. **Binding Agreement**. This Agreement shall bind and inure to the benefit of the parties, their successors and assigns.
- 7. **Governing Law**. It is agreed that this Agreement shall be governed by, construed, and enforced with the laws of the State of Indiana.
- 8. Entire Agreement. This Agreement shall constitute the entire agreement between the parties. Any prior understanding or representation of any kind preceding the date of this Agreement shall not be binding upon either party, to the extent incorporated in this Agreement.

 Agreement.

 See the attached addendum

9. **Modification of Agreement**. Any modification of this Agreement or additions obligation assumed by either party in connection with this Agreement will be binding only if made in writing and signed by each party or an authorized representative of each party.

10. **Paragraph Headings**. The titles to the paragraphs of this Agreement are solely for the convenience of the parties, and shall not be used to explain or modify the provisions of the Agreement.

IN WITNESS WHEREOF, each party of, 2008.	f this Agreement has executed it on <u>ਕੀ^{ਤੀ}</u> day o
PROPERTY STREET ADDRESS 53588 Kershr	ner Ln., Elkhart, IN 46514
CHECK ONE	
I/We do want a hookup to the water s	system extension being provided by Geocel.
I/We do NOT want a hookup to the w	vater system extension being provided by Geocel.
	Homeowner's Signature Homeowner's Name (Printed) Homeowner's Signature
	Homeowner's Name (Printed)
Geocel Holdings Corporation	
By: Stall	

4

Document2

ADDENDUM

Notwithstanding any provision to the contrary in the Agreement to which this Addendum is attached and made a part, the Utility Petitioner/Homeowner hereby reserves all rights and claims they may have against one or more of the Geocel defendants (as identified in the litigation Pending in Elkhart Circuit Court as Cause No.20C01-0802-CT-07, hereinafter the "Litigation") in the Litigation to recover all costs, expenses and liabilities arising from and/or relating in any way to the installation of and connection to public water supplies for the Utility Petitioner/Homeowner's residence, including by way of example and not limitation, the monthly water user's fees for public water service and any expenses incurred for the maintenance of water service lines (collectively, the "Retained Claims"). Execution by the Utility Petitioner/Homeowner of the Residential Compact Agreement and the Temporary Easement Agreement shall not constitute a waiver of the Retained Claims.

Hatricia H. Utility Petitioner/Ho	y	uller)
Utility Petitioner/Ho	omeow	mer's Sig	nature
Patricia	A.	Mi 1/2	ER_
Printed Name		•	
			
Utility Petitioner/He	omeow	ner's Sig	nature
Printed Name			

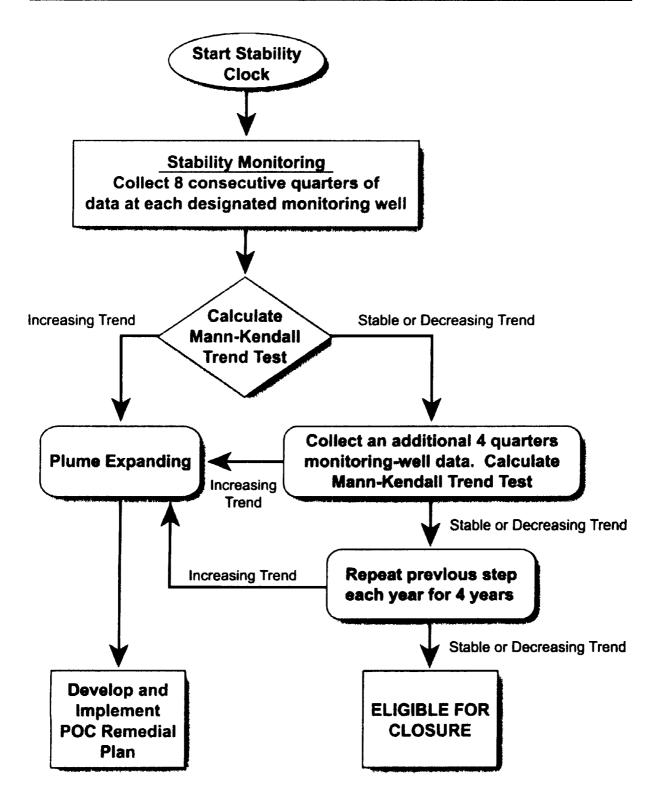


Figure A.3-2. Stability Monitoring Closure for Ground Water Contaminant Plumes

